STANFORD ARTIFICIAL INTELLIGENCE LABORATORY
OPERATING NOTE 28.6

STANFORD LISP 1.6 MANUAL

by

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ABSTRACT: This manual describes the PDP-10 LISP 1.6 system developed by the Stanford Artificial Intelligence Project. The manual is not a tutorial on LISP but is intended to supplement existing LISP tutorials in order to prepare one to understand and use this LISP system.

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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U.S. Government.

PREFACE

This manual is the result of several relatively minor changes and additions to SAILON 28.4. It supercedes and replaces SAILONS 1, 4, 28.2-4, and 41.

The changes reflect changes in LISP and may be summarized as follows:

The allocation procedure, and LISP initialization have been changed; Sections 2.1 and 2.2.

There are some new debugging facilities in Appendix N and the documentation for some old ones has been put into the manual.

The compiler has been revised, and is described in a greatly expanded Appendix F.

Acknowledgment

The STANFORD A.I. Lisp 1.6 System was originally an adaptation of one developed by the Artificial Intelligence Project at M.I.T. Since 1966, that system has been largely rewritten by John Allen and Lynn Quam.

John R. Allen implemented the storage reallocation system which makes it possible for the user to change the sizes of the various memory spaces. He also designed and coded the editor ALVINE, wrote the first loader interface, and generally maintained and debugged the system. John Allen contributed the ALVINE documentation in Appendix A.

Marilyn Mullins has assisted in the preparation of the present edition.

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CHAPTER 1

INTRODUCTION

This manual is intended to explain the interactive LISP 1.6 system which has been developed for the PDP-10 at the Stanford University Artificial Intelligence Project. It is assumed that the reader is familiar with either some other LISP system or the LISP 1.5 PRIMER by Clark Weissman[2].

The LISP 1.6 system described has as a subset most of the features and functions of other LISP 1.5 systems. In addition, there are several new features such as an arbitrary precision integer package, an S-expression editor, up to 14 active input-output channels, the ability to control the size of memory spaces, a standard relocating loader to load assembly language or compiled programs, etc.

This system uses an interpreter; however, there is also a compiler which produces machine code. Compiled functions are approximately 20 times as fast and take less memory space.

This manual is organized in a functional manner. First the basic data structures are described; then the functions for operating on them. The appendices present more detailed information on the system, its internal structure, the compiler, and several auxiliary packages.

1.1 Guide to the Novice

The user who is not experienced with any LISP system is advised to follow the instructions below:

1) Become familiar with Weissman's LISP 1.6 Primer[2] or some equivalent introductory LISP Manual.

2) Learn the document conventions (1.4).

3) Become superficially familiar with LISP 1.6 identifiers, numbers and S-expressions (Chapters 3,4, and 5).

4) Understand the most useful functions: Those preceded by exclamation marks "!" in chapters 6 through 14.

5) Learn how to define functions (6.1).

6) Learn how to interact with LISP (Chapter 2).

7) Try some examples. Weissman[1] has some good problems.

8) Learn what other useful functions and features are available (1.3).

1.2 Guide to the User Experienced with Another LISP System

The user who has used another LISP system is advised to follow these instructions:

1) Learn the document conventions (1.4).

2) Learn top level of LISP 1.6 is EVAL, not EVALQUOTE.

3) Use DE, DF and DEFPROP for defining functions. (Section 11.1).

4) Many functions differ from those in other systems. Most of these are noted in the index.

5) The syntax of atoms is different from other systems (chapters 3 and 4).

6) Learn how to interact with LISP (Chapter 2).

7) Try some examples.

8) Learn what other useful functions and features are available (1.3).

1.3 Guide to Useful Functions and Features

The following is a partial list of useful features and functions in LISP 1.6 and what they might be useful for.

1) ALVINE (Appendix A) is useful for editing functions and manipulating I/O files.

2) READ has some very useful control characters (Section 14.3).

3) Input/Output (Chapter 14) is very flexible.

4) One can control error messages (Chapter 16).

5) There is a LISP compiler (Appendix F) which generates code that runs approximately twenty times as fast as interpreted functions.

6) There are auxiliary files on the disk which are often useful:

filename	use	document
SYS:SMILE	file manipulation	Appendix O
SYS:TRACE	tracing functions and setqs	Appendix N
SYS:SOSLNK	rapid turn-around between SOS and LISP	Appendix K
SYS:LISPDP.LSP	III display functions	Appendix M
LISP.COR[S,DOC]	corrections to this manual	

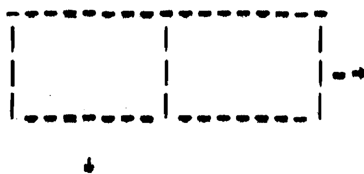
7) One can load and link LISP to assembly and Fortran compiled programs. See Appendix H.

8) One can have files automatically loaded by use of the file INIT.LSP which is automatically loaded on entry.

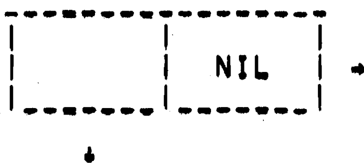
1.4 Document Conventions

1.4.1 Representation Conventions

In the description of data structures, the following notational conventions will be used.



represents a 36-bit word in FREE STORAGE with 2 18-bit pointers.



represents the last word in a list.

represents a 36-bit word in FULL WORD SPACE.

1.4.2 Syntax Conventions

A slightly modified form of BNF is used to define syntax equations. Optional terms are surrounded by curly brackets { and }.

1.4.3 Calling Sequence Conventions

Calling sequences to LISP functions are presented in S-expression form, with the CAR of the S-expression being the name of the function. An argument to a function is evaluated unless that argument is surrounded by quotes (") in the calling sequence definition. Quotes mean that the function implicitly QUOTEs that argument.

Examples: (SETQ "ID" V) ID is not evaluated, but V is evaluated.

(QUOTE "V") V is not evaluated.

1.4.4 Other Conventions

The blank character (ASCII 40) is indicated by "_" when appropriate for clarity.

A special notation in the left margin is used to indicate the degree of utility or difficulty of each section of this manual:

mark	meaning
!	basic
<no mark>	generally useful
*	useful but more sophisticated
#	not generally useful

CHAPTER 2

INTERACTIVE USE OF THE SYSTEM

2.1 Using the System

The following dialog shows how to log into the time-sharing system, start the LISP system, and interact with the top level of LISP. Lines beginning with period are typed by the user to the time-sharing system, and the lines beginning with asterisk are typed to LISP. The symbol <cr> specifies carriage-return, and $ means altmode.

```
.L
#1,FOO
↑C

.R LISP
```

FREE STORAGE = 10000 = 20000 <cr> — This gives 20K of Free Storage instead of the usual 10K.

FULL WORDS = 4000 = <cr> — This gives the default value of 5K.

BIN. PROG. SP. = 2000 = 12000$ — This gives 12K of Binary Program Space, and ends the allocation.

For a full discussion of allocation see Appendix C.

Digression:

At this point, after allocation and before anything else, the file LISP.LSP is read from the system. This defines various macros, recent additions to the system, bootstrap definitions for the functions in the various self loading utility files, Trace, SOSLNK, LAP etc. In addition, if there is a file by the name INIT.LSP in the user's directory, it will be loaded too. This enables the user to have anything he likes loaded automatically.

To continue:

```
T<altmode>
T                    T and NIL always evaluate to themselves.
*(QUOTE (A B C)) <carriage return>
(A B C)                     Value of QUOTE
(CONS 1 (QUOTE A)) <carriage return>

(1 . A)                     Numbers always evaluate to themselves
                            and thus need not be quoted.

<a long sequence of output>     This output can be suppressed with ↑O.
```

```
*(DEFPROP CDRQ (LAMBDA (L) (CDAR L)) FEXPR) <carriage return>

CDRQ

*(CDRQ CAR) <carriage return>

(SUBR #address PNAME (#fullword))

*(DE TWICE (NUM) (TIMES 2 NUM)) <carriage return>

TWICE

*(TWICE 3) <carriage return>

6

>etc.>
```

2.2 Special Teletype Control Characters

The time-sharing system treats many control characters in special ways. For a complete discussion of control characters see the PDP-10 TIME SHARING MONITOR MANUAL. Briefly, the following special control characters are used in LISP.

Teletype	III Display	Meaning
↑C	CALL	Stop the job and talk to time-sharing system.
↑O	Control 2 linefeed	Suppress console printout until an input is requested.
↑U	Control 1 linefeed	Delete the entire input line now being typed. (Only with (DDTIN NIL)).
↑G(BELL)	*	Stop the LISP interpreter and return control to the top level of LISP. Only effective when LISP is asking for console input. See INITFN (16).
rubout	BS	Delete the last character typed. (For (DDTIN T) see 14-3.

CHAPTER 3

IDENTIFIERS

Identifiers are strings of characters which taken together represent a single atomic quantity.

Syntax:

<comments> ::=<ASCII 32> <any sequence of characters not including line-feed> <line feed>
<delimiter> ::= (|) | [|] | ? |@|/|"| <blank> | <altmode> | carriage-return | <line-feed> | <tab> | <form-feed>
<character>::= <any extended ASCII character other than null and ASCII 176>
<digit>::= Ø|1|2|3|4|5|6|7|8|9
<letter>::= <any character not a digit and not a delimiter>
<identifier>::= <letter>
::=<identifier> <digit>
::= / <character>
::= <identifier>/<character>

Semantics:

Identifiers are normally strings of characters beginning with a letter and followed by letters and digits. It is sometimes convenient to create identifiers which contain delimiters or begin with digits. The use of the delimiter "/" (slash) causes the following character be taken literally, and the slash itself is not part of the identifier. Thus, /AB is the same as AB is the same as /A/B.

Comments are useful for allowing descriptive text in files which will be completely ignored when read. Comments also make it possible to extend atoms (identifiers, strings and numbers) across nine boundaries without any of the characters in the comment becoming part of the atom.

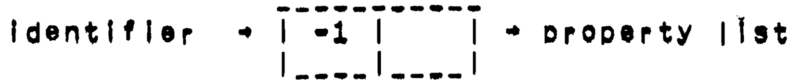
ASCII 32 cannot be typed directly into LISP. In STOPGAP, ?3 designates ASCII 32. On the line printer and III displays, ASCII 32 prints as tilde "~". ASCII 32 does not print on teletypes. (See CHRCT in 14.1.4.)

Examples:

A	/(
a	?
FOObaz	/13245
TIME-OF-DAY	/,
A1B2	LPT:

Representation:

An identifier is internally represented as a dotted pair of the following form:



which is called an atom header.

Thus CDR of an identifier gives the property list of the identifier, but CAR of an identifier gives the pointer 777777, which if used as an address will cause an illegal memory reference, and an error message. An identifier is referred to in symbolic computation by the address of its atom header.

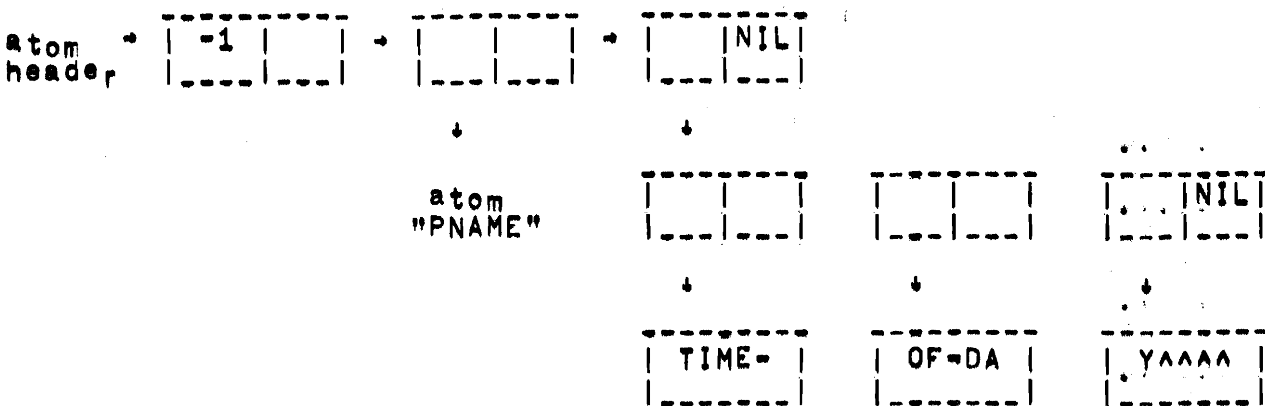
3.1 Property Lists

The property list of an identifier is a list of pairs: (property name, property value) associated with that identifier. The normal kinds of properties which are found in property lists are print names, values, and function definitions corresponding to identifiers.

3.1.1 Print Names

Every identifier has a print name (PNAME) on its property nist. The print name of an identifier is a list of full words, each containing five ASCII characters.

Example: The identifier TIME-OF-DAY would be initially represented as follows:

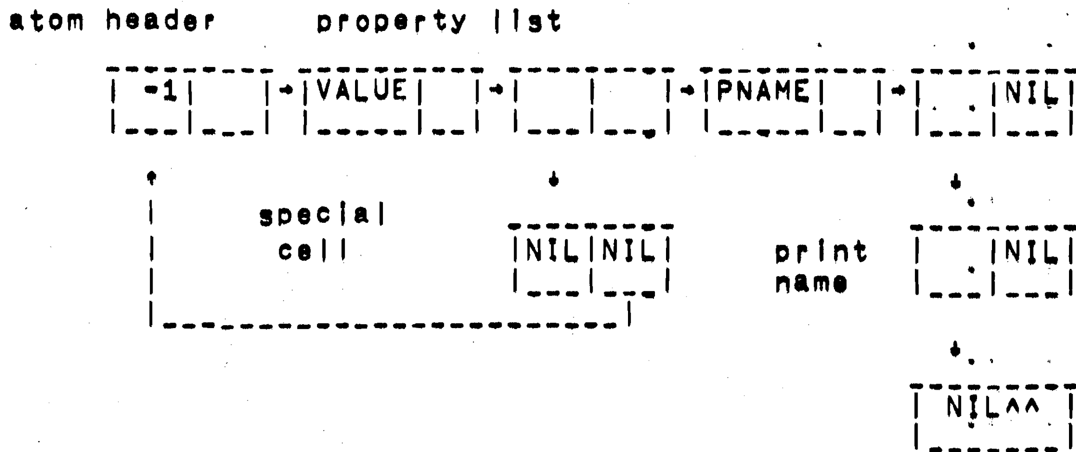


where ^ means null or ASCII Ø.

3.1.2 Special Cells

When a value is assigned an identifier, the property name VALUE is put on the identifier's property list with property value being a pointer vo a special cell. The CDR of the special cell (sometimes called VALUE cell) holds the value of the identifier, and the address of a special cell remains constant for that identifier unless REMPROPed (11.2), to enable compiled functions to directly reference the values of special variables. Global variables and all variables bound in interpreted functions store their values in special cells.

Example: The atom NIL has the following form:



3.2 The OBLIST

In order that occurrences of identifiers with the same print names have the same internal address (and hence value), a special nist which is the VALUE of a global variable called OBLIST is used to remember all identifiers which READ and some other functions have seen. For the sake of searching efficiency, this list has two nevels: the first level contains sequentially stored "buckets" which are "hashed" into as a function of the print name of the identifier. Each bucket is a list of all distinct identifiers which have hashed into that bucket. Thus, (CAR OBLIST) is the first bucket, and (CAAR OBLIST) is the first identifier of the first bucket.

3.3 Strings

Syntax:

string::= "<any sequence of characters not containing ">"

Semantics

A string is an arbitrary sequence of characters surrounded by double quotes and not containing double quotes. Strings are represented identically to identifiers except that strings are not automatically INTERNed on the OBLIST. The double quotes surrounding strings actually become part of the PRINT NAME of the string unlike slashes in slashified identifiers.

Examples:

```
"I AM A STRING"
"1,3-X 5"
```

CHAPTER 4

NUMBERS

There are two syntactic types of numbers: integer and real.

```
<number>          ::= <integer> | <real>
```

4.1 Integers

Syntax:

```
<integer>     ::= (<sign>) <digits> (.)

<digits>      ::= <digit> (<digits>)

<sign>        ::=  +|-
```

Semantics:

The global variable IBASE specifies the input radix for integers which are not followed by "." Integers followed by "." are decimal integers. IBASE is initially = 8. Similarly, the global variable BASE controls output radix for integers. If BASE = 10 then integers will print with a following ".", unless the global variable *NOPOINT = T.

Examples with IBASE = 8

input			meaning
-13	=	-11	= -11↓10
1000	=	512	=+512↓10
19	=	17	= +17↓10

Representation:

There are three representations for integers depending on the numerical magnitude of the integer: INUM, FIXNUM, and BIGNUM. Their ranges are as follows:

INUM		|n| <K	K is usually 2↑16
FIXNUM	K≤	|n| <2↑35	
BIGNUM	2↑35 ≤	|n|	

Representation of INUMs:

INUMs are small integers represented by pointers outside of the normal LISP addressing space. INUMs are addresses in the range 2↑18-2K to 2↑18-2. The INUM representation for zero is α = 2↑18-K-1.

Examples	INUM	Representation
	-(K-1)	α - (K-1)
	-1	α - 1
	Ø	α = 2↑18-K-1
	1	α + 1
	K-1	α + K-1

Representation of FIXNUMs:

FIXNUMs are represented by list structure of the following form:

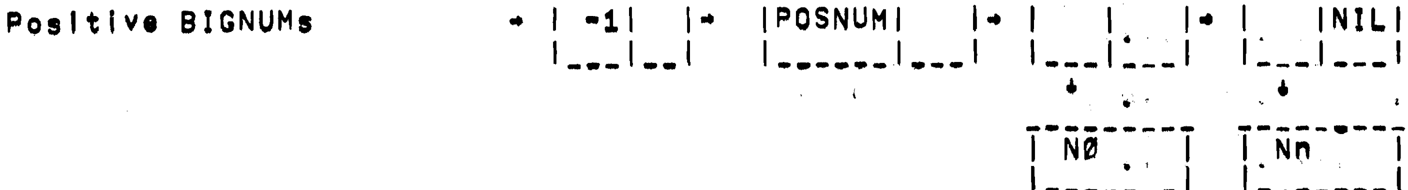
Atom header

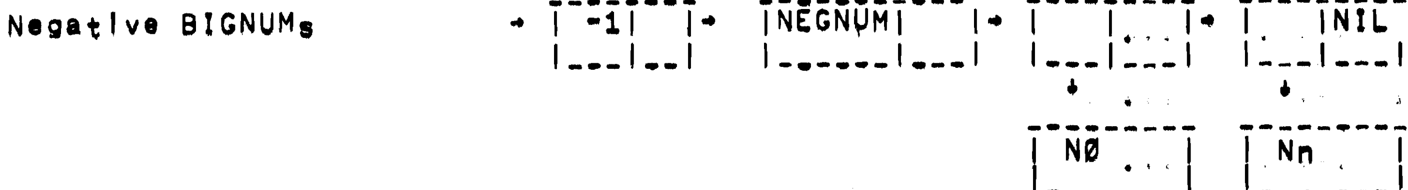
where value is the 2's complement representation of the fixed point number.

Examples:

Representation of BIGNUMs

BIGNUMs are represented by list structure of the following forms:





where N_i are positive 36 bit integers ordered from least to most significant. The value of a BIGNUM is

$$sign * (N_0 + 2^{35} N_1 + 2^{35*2} N_2 + ... + 2^{35n} N_n)$$

Note: BIGNUMs are not normally a part of the interpreter. Appendix H describes the procedures for loading the BIGNUM package.

4.2 Reals

Syntax:

```
<real>          ::= (<sign>)  <digits> (.) <exponent>
                ::= (<sign>) (<digits>) .  <digits> (<exponent>)
<exponent>      ::= E (<sign>)  <digits>
```

Examples:

	meaning
3.14159	+3.14159
+1E-3	+0.001
-196.37E4	-1963700.0
0.3	+0.3
-0.3E+1	-3.0

Restrictions:

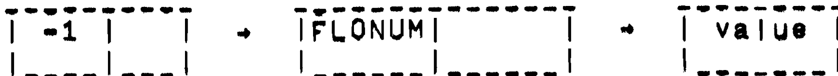
The radix for real numbers is always decimal. A real number x must be in the (approximate) range:

$$10^{-38} < |x| < 10^{+38} \quad \text{or } x = 0$$

A real number has approximately eight significant digits of accuracy.

Representation:

atom header



where value is in PDP-6/10 2's complement floating point representation.

CHAPTER 5

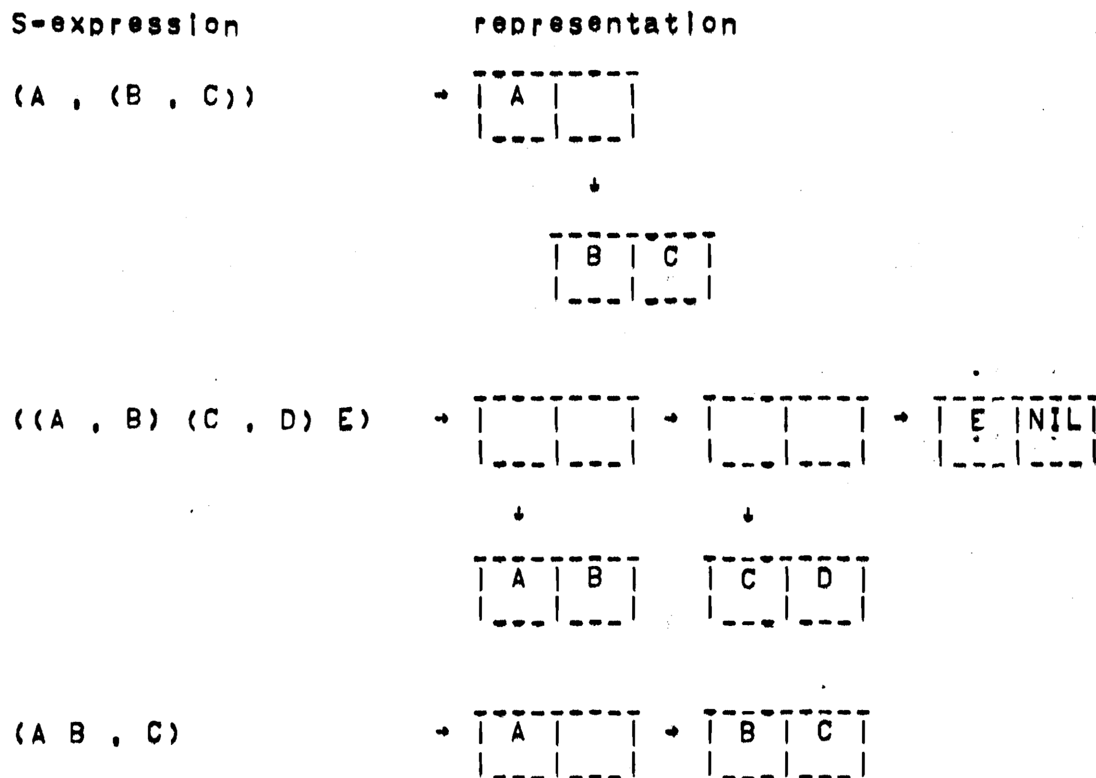
S-EXPRESSIONS

Syntax:

<atom> ::= <identifier> | <string> | <number>

<S-expression> ::= <atom>
 ::= (<S-expression list>(*<S-expression>))
 ::= ( ) = NIL
<S-expression list> ::= <S-expression>
 ::= <S-expression> <S-expression list>

Representation:



Exceptions:

The identifier NIL is the identifier which represents the empty list, i.e., ().

CHAPTER 6

LAMBDA EXPRESSIONS

LAMBDA expressions provide the means of constructing computational procedures (often called functions, subroutines, or procedures) which compute answers when values are assigned to their parameters. A LAMBDA expression can be bound to an identifier so that any reference to that identifier in functional context refers to the LAMBDA expression. In LISP 1.6 there are several types of function definition which determine how arguments are bound to the LAMBDA expression. The following is a LAMBDA expression:

! (LAMBDA "ARGUMENT-LIST" "BODY")

LAMBDA defines a function by specifying an ARGUMENT-LIST, which is a list of identifiers (except for LEXPRs, see 6.3) and a BODY, which is an S-expression. LAMBDA expressions may have no more than five arguments if they are to be compiled.

Examples: (LAMBDA NIL 1)
This LAMBDA expression of no arguments always evaluates to one.

(LAMBDA (X) (TIMES X X))
This LAMBDA expression computes the square of its argument, if x is a number. Otherwise an error will result.

(LABEL "ID" "LAMBDA-EXPR")

LABEL creates a temporary name ID for its LAMBDA expression. This makes it possible to construct recursive functions with temporary names.

Example:

```
(DE REVERSE (L)
    ((LABEL REVEVSE1
          (LAMBDA (L M)
                (COND ((ATOM L) M)
                      (T (REVERSE1 (CDR L) (CONS (CAR L) M))))))
     L NIL))
```

LAMBDA expressions are evaluated by "binding" actual arguments to dummy variables of the LAMBDA expression, (see Chapter 14) then evaluating the body inside the LAMBDA expression with the current dummy variable bindings. However, actual arguments to LAMBDA expressions are handled in a variety of ways. Normally, there is a one-to-one correspondence between dummy variables and actual arguments, and the actual arguments are evaluated before they are

bound. However, there are three special forms of function definition which differ in their handling of actual arguments.

! 6.1 EXPRs and SUBRs

An EXPR is an identifier which has a LAMBDA expression on its property list with property name EXPR. EXPRs are evaluated by binding the values of the actual arguments to their corresponding dummy variables. DE (see 11.1) is useful for defining EXPRs. The compiled form of an EXPR is a SUBR.

Examples:

```
(DE SQUARE (X) (TIMES X X))
(DE *MAX (X Y) (COND ((GREATERP X Y) X) (T Y)))
```

6.2 FEXPRs and FSUBRs

A FEXPR is an identifier which has a LAMBDA expression of one dummy variable on its property list with property name FEXPR. FEXPRs are evaluated by binding the actual argument list to the dummy variable without evaluating any arguments. DF (see 11.1) is useful for defining FEXPRs. The compiled form of an FEXPR is an FSUBR.

Examples:

```
(DF LISTQ (L) L)
        (LISTQ A (B) C) = (A (B) C)
        (LISTQ) = NIL
(DF DEFINE (L)
        (MAPC (FUNCTION (LAMBDA (X) (PUTPROP (CAR X)
                                             (CADR X)
                                             (QUOTE EXPR))))
              L))
        (DEFINE (LEQ (LAMBDA (X Y) (OR (LESSP X Y)
                                       (EQUAL X Y))))
                (GEQ (LAMBDA (X Y) (OR (GREATERP X Y)
                                       (EQUAL X Y)))))
```

6.3 LEXPRs and LSUBRs

An LEXPR is an EXPR whose LAMBDA expression has an atomic argument "list" of the form:

```
(LAMBDA "ID" "FORM")
```

LEXPRs may take an arbitrary number of actual arguments which are evaluated and referred to by the special function ARG. ID is bound vo the number of arguments which are passed. The compiled form of an LEXPR is an LSUBR.

(ARG N)

ARG returns the value of the Nth argument to an LEXPR.

Example:

```
(DE MAX N
   (PROG (M)
         (SETQ M (ARG N))
       L (SETQ N (SUB1 N))
         (COND ((ZEROP N) (RETURN M))
               ((GREATERP (ARG N) M) (SETQ M (ARG N))))
         (GO L)))
(MAX 1 1.2 4 3 -50) = 4
```

(SETARG N V)

SETARG sets the value of the Nth argument to V and returns V.

6.4 MACROs

A MACRO is an identifier which has a LAMBDA expression of one dummy variable on its property list with property name MACRO. MACROs are evaluated by binding the list containing the macro name and the actual argument list to the dummy variable. The body in the LAMBDA expression is evaluated and should result in another "expanded" form. In the interpreter, the expanded form is evaluated. In the compiler, the expanded form is compiled. DM(see 11.1) is useful for defining MACROs.

Examples:

1) We could define CONS of an arbitrary number of arguments by:

```
(DM CONSCONS (L)
    (COND ((NULL (CDDR L)) (CADR L))
          (T (LIST (QUOTE CONS)
                   (CADR L)
                   (CONS (QUOTE CONSCONS) (CDDR L))))))
```

(CONSCONS A B C) would call CONSCONS with L = (CONSCONS A B C). CONSCONS then forms the list (CONS A(CONSCONS B C)). Evaluating this will again call CONSCONS with L = (CONSCONS C). CONSCONS will finally return C.

The effect of (CONSCONS A B C) is then (CONS A (CONS B C)).

2) We could define a function EXPAND which is more generally useful for MACRO expansion:

```
(DE EXPAND (L FN)
    (COND ((NULL (CDR L)) (CAR L))
          (T (LIST FN (CAR L) (EXPAND (CDR L) FN)))))
```

Then we could define CONSCONS:

```
(DM CONSCONS (L) (EXPAND (CDR L) (QUOTE CONS)))
```

It should be noted that MACROs are more general than FEXPRs and LEXPRs. In fact the previous definitions can be replaced by the following MACROs:

```
(DM LISTQ (L) (LIST (QUOTE QUOTE) (CDR L))))
(DM MAX (L) (EXPAND (CDR L) (QUOTE *MAX)))
        (MAX A B C D) would expand to:
        (*MAX A (*MAX B (*MAX C D)))
```

3) (*EXPAND L FN)
   (*EXPAND1 L FN)

*EXPAND and *EXPAND1 are MACRO expanding functions used by PLUS, TIMES, etc. They are equivalent to:

```
(DE *EXPAND (L FN) (*EXPAND1 (REVERSE (CDR L)) FN))
(DE *EXPAND1 (L FN)
  (COND ((NULL (CDR L)) (CAR L))
     (T (LIST FN (*EXPAND1 (CDR L) FN) (CAR L)))))
```

Example:

With PLUS defined as

```
(DM PLUS (L) (*EXPAND L(QUOTE *PLUS)))
(PLUS A B C D) expands to:
   (*PLUS (*PLUS (*PLUS A B) C) D)
```

CHAPTER 7

EVALUATION OF S-EXPRESSIONS

This chapter describes the heart of the LISP interpreter, the mechanism for evaluating S-expressions.

! (*EVAL E)
(EVAL E)

*EVAL and EVAL (see 7.2) evaluate the value of the S-expression E.

Examples:

```
        (EVAL (LIST (QUOTE ADD1) 3)) = 4
The top level of LISP is:
        (PROG NIL
         L    (PRINT (EVAL (READ))) (TERPRI) (GO L))
```

! (APPLY FN ARGS)

APPLY evaluates and binds each S-expression in ARGS to the corresponding arguments of the function FN, and returns the value of FN. See 7.2.

Example:

```
        (APPLY (FUNCTION APPEND) (QUOTE ((A B) (C D)))) = (A B C D)
```

! (QUOTE "E")

QUOTE returns the S-expression E without evaluating it.

(FUNCTION "FN")

FUNCTION is the same as QUOTE in the interpreter. In the compiler, FUNCTION causes the S-expression FN to be compiled, but QUOTE generates an S-expression constant. See *FUNCTION in 7.2 for the special FUNARG feature.

The folnowing function definitions lack some details but explain the essence of EVAL and APPLY. The A-LIST feature of these functions is not shown, but will be explained in 7.2.

```
(DE EVAL (X)
    (PROG (Y)
       (RETURN
         (COND ((NUMBERP X) X)
               ((ATOM X) (COND ((SETQ Y (GET X (QUOTE VALUE)))
                                 (CDR Y))
                                (T (ERR (QUOTE (UNBOUND VARIABLE))))))
```

```
((ATOM (CAR X))
 (COND ((SETQ Y (GETL (CAR X) (QUOTE EXPR FEXPR MACRO))))
                (COND ((EQ (CAR Y) (QUOTE EXPR))
                       (APPLY (CADR Y)
                              (MAPCAR (FUNCTION EVAL) (CDR X
                      ((EQ (CAR Y) (QUOTE FEXPR)
                       (APPLY (CADR Y) (LIST (CDR X))))
                      (T (EVAL (APPLY (CADR Y) (LIST X))))))
               ((SETQ Y (GET (CAR X) (QUOTE VALUE)))
                (EVAL (CONS (CDR Y) (CDR X))))
               (T (ERR (QUOTE (UNDEFINED  FUNCTION))))))
        (T (APPLY (CAR X) (MAPCAR (FUNCTION EVAL) (CDR X))))

(DE APPLY (FN ARGS)
   (COND ((ATOM FN)
          (COND ((GET FN (QUOTE EXPR))
                 (APPLY (GET FN (QUOTE EXPR)) ARGS))
                (T (APPLY (EVAL FN) ARGS))))
         ((EQ (CAR FN) (QUOTE LAMBDA))
          (PROG (Z)
                (BIND (CADR FN) ARGS)
                (SETQ Z (EVAL (CADDR FN)))
                (UNBIND (CADR FN))
                (RETURN Z)))
         (T (APPLY (EVAL FN) ARGS))))
```

The functions BIND and UNBIND implement variable bindings as described in the next section.

• 7.1 Variable Bindings

This section attempts to explain the different types of variable bindings and the difference between interpreter and compiler bindings.

• 7.1.1 Bound and Free Occurrences

An occurrence of a variable is a "bound occurrence" if the variable is a variable in any LAMBDA or PROG containing the occurrence so long as the occurrence is not contained in a FUNCTIONAL argument which is contained in the defining LAMBDA or PROG. The defining LAMBDA or PROG is the innermost LAMBDA or PROG which contains the variable in its parameter list.

Examples:

```
(LAMBDA (X) (TIMES X Y))
        X has a bound occurrence.
        Y has a free occurrence.
(LAMBDA (Y Z) (MAPCAR (FUNCTION (LAMBDA(X) (CONS X Y)))Z)
        X and Z have only bound occurrences.
        Y is bound by the outer LAMBDA and free in the inner.
```

* 7.1.2 Scope of Bindings

A variable bound in a LAMBDA or PROG is defined during the dynamic execution of the LAMBDA or PROG. Free occurrences of variables are defined if and only if either the variable is globally defined or the variable is bound in any LAMBDA or PROG which dynamically contains the free occurrence. A variable is globally defined if and only if it has a value at the top level of LISP. variables can be globally defined by SETQ at the top level.

* 7.1.3 Special Variables

In compiled functions, any variable which is bound in a LAMBDA or PROG and has a free occurrence elsewhere must be declared SPECIAL (APPENDIX E).

Example:

```
        (LAMBDA (A B)
                (MAPCAR (FUNCTION (LAMBDA (X) (CONS A X))) B))
```

The variable A which has a free occurrence must be declared SPECIAL if the outer LAMBDA expression is to be compiled.

* 7.1.4 Binding Mechanisms

All variables in interpreted functions, and SPECIAL variables in compiled functions store their values in SPECIAL (or VALUE) cells. These variables are bound at the entry to a LAMBDA or PROG by saving their previous values on the SPECIAL pushdown list and storing their new values in the SPECIAL cells. All references to these variables are directly to their SPECIAL cells. When the LAMBDA or PROG is exited, the old values are restored from the SPECIAL pushdown list.

In compiled functions, all variables not declared SPECIAL are stored on the REGULAR pushdown list, and the SPECIAL cells (if they exist) are not referenced.

7.2 The A-LIST and FUNARG Features

The A-LIST which is used in some LISP systems to implement recursive variable bindings does not exist here, but its effects are simulated through a special A-LIST feature. The functions EVAL and APPLY allow an extra last argument to be passed which is either a nist of paired identifiers and values (like an A-LIST) or a "binding context pointer".

In the case of an A-LIST second argument, EVAL and APPLY will bind the special cells of the variables in the A-LIST to their specified values, saving their previous bindings on the special pushdown list. When EVAL and APPLY return, the variable bindings are restored to their previous values.

A "binding context pointer" (BCP) is a pointer into the SPECIAL PUSHDOWN LIST designating a level in recursive variable binding. When EVAL and APPLY receive a BCP as their second argument, all SPECIAL (VALUE) CELLS are restored to the values they had at the vime the BCP was generated. This then causes EVAL and APPLY to reference these variables in the binding context which existed at the vime of BCP generation. This feature primarily is useful to prevent variable name conflicts when using EVAL, APPLY, and functional arguments. As with the A-LIST, when EVAL and APPLY exit, the previous bindings are restored.

There are two ways to generate a BCP:

If an FEXPR is defined with two arguments, then the second argument will be bound to the SPECIAL PUSHDOWN LIST level at the time the FEXPR is called.

The second way to generate a BCP is with *FUNCTION.

(*FUNCTION "FN")

*FUNCTION returns a list of the following form:

(FUNARG FN * <BCP>)

where BCP is the SPECIAL PUSHDOWN LIST level at the time *FUNCTION is called. Whenever such a functional form is used in functional context, all SPECIAL bindings are restored to the values they had at the time *FUNCTION was evaluated. When the functional argument has been ApPLYed, the previous bindings are restored as with the A-LIST.

The use of FUNARGS is discussed further by Robert Saunders[3].

Example using the BCP feature:

```
(DF EXCHANGE (L SPECPDL)
    (PROG(Z) (SETQ Z(EVAL (CAR L) SPECPDL))
             (APPLY (FUNCTION SET)
                    (LIST (CAR L) (EVAL (CADR L) SPECPDL)
                     SPECPDL)
             (APPLY (FUNCTION SET)
                    (LIST (CADR L) Z
                     SPECPDL)))
```

In this example, the use of the extra argument SPECPDL has only one effect: to avoid conflicts between internal and external variables with names L and SPECPDL.

(EXCHANGE L M) will cause the values of L and M to be exchanged. The variable L in EXCHANGE is not referenced by the calls on SET.

CHAPTER 8

CONDITIONAL EXPRESSIONS

A conditional expression has the following form:

! (COND ($e_{1,1}$ $e_{1,2}$ ... e_{1,n_1})

($e_{2,1}$ $e_{2,2}$ ... e_{2,n_2})

...

($e_{m,1}$ $e_{m,2}$ ... e_{m,n_m}))

where the $e_{i,j}$'s are any S-expressions.

The $e_{i,1}$'s are considered to be predicates, i.e., evaluate vo a truth value. The $e_{i,1}$'s are evaluated starting with $e_{1,1}$, $e_{2,1}$, etc., until the first $e_{k,1}$ is found whose value is not NIL. Then the corresponding $e_{k,2}$ $e_{k,3}$ ...e_{k,n_k} are evaluated respectively and the value of e_{k,n_k} is returned as the value of COND. It is permissible for n_k =1, in which case the value of $e_{k,1}$ is the value of COND. If all $e_{i,1}$ evaluate to NIL, then NIL is the value of COND.

Examples:

```
(DE NOT (X) (COND (X NIL) (T)))
(DE AND (X Y) (COND (X (COND (Y T)))))
(DE OR (X Y) (COND (X T) (Y T)))
(DE IMPLIES (X Y) (COND (X (COND (Y T))) (T)))
```

CHAPTER 9

PREDICATES

Predicates test S-expressions for particular values, forms, or ranges of values. All predicates described in this chapter return either NIL or T corresponding to the truth values false and true, unless otherwise noted. Some predicates cause error messages or undefined results when applied to S-expressions of the wrong type, such as (MINUSP (QUOTE FOO)).

! (ATOM X)

The value of ATOM is T if X is either an identifier or a number; NIL otherwise.

```
Examples:       (ATOM T)               = T
                (ATOM 1.23)            = T
                (ATOM (QUOTE (X Y Z))) = NIL
                (ATOM (CDR (QUOTE (X)))) = T
```

! (EQ X Y)

The value of EQ is T if X and Y are the same pointer, i.e., the same internal address. Identifiers on the OBLIST have unique addresses and therefore EQ will be T if X and Y are the same identifier. EQ will also return T for equivalent INUMs, since they are represented as addresses. However, EQ will not compare equivalent numbers of any other kind. For non-atomic S-expressions, EQ is T if X and Y are the same pointer.

```
Examples:       (EQ T T)               = T
                (EQ T NIL)             = NIL
                (EQ (QUOTE A)   (QUOTE B))       = NIL
                (EQ 1 1.Ø)             = NIL
                (EQ 1 1)               = T
                (EQ 1.Ø 1.Ø)           = NIL
```

(EQUAL X Y)

The value of EQUAL is T if X and Y are identical S-expressions. EQUAL can also test for equality of numbers of mixed vypes. EQUAL is equivalent to:

```
(LAMBDA(X Y) (COND ((EQ X Y) T)
                   ((AND (NUMBERP X) (NUMBERP Y))
                    (ZEROP (*DIF X Y)))
                   ((OR (ATOM X)(ATOM Y)) NIL)
                   ((EQUAL (CAR X) (CAR Y))
                    (EQUAL (CDR X) (CDR Y)))))
```

```
Examples:         (EQUAL T T)       = T
                  (EQUAL 1 1)       = T
                  (EQUAL 1 1.0)     = T
                  (EQUAL (QUOTE (A B)) (QUOTE (A B)))     = T
                  (EQUAL (QUOTE (T)) T)             = NIL
```

! 9.1 S-Expression Predicates

```
(NULL L)          = T if and only if L is NIL.

(MEMBER L1 L2)    = T if and only if L1 is EQUAL to a top level element of L2
```

MEMBER is equivalent to:

```
        (LAMBDA(L1 L2) (COND ((ATOM L2) NIL)
                             ((EQUAL L1 (CAR L2))T)
                             (T(MEMBER L1 (CDR L2)))))
```

```
Examples:         (MEMBER (QUOTE (C D)) (QUOTE ((A B)(C D)E)))    = T
                  (MEMBER (QUOTE C)(QUOTE (C)))) = NIL

(MEMQ L1 L2)      = T iff L1 is EQ to a top level element of L2.
```

MEMQ is equivalent to:

```
        (LAMBDA(L1 L2)(COND ((ATOM L2) NIL)
                            ((EQ L1 (CAR L2)) T)
                            (T(MEMQ L1 (CDR L2)))))
```

```
Examples:         (MEMQ (QUOTE (C D))(QUOTE ((A B)(C D) E))) = NIL
                  (MEMQ (QUOTE A) (QUOTE (Q A B))) = T
```

! 9.2 Numerical Predicates

```
(NUMBERP X)       = T if X is a number of any type
                  = Nil otherwise

(ZEROP X)         = T if X is zero of any numerical type
                  = error if X is a non-numerical quantity
                  = NIL otherwise

(MINUSP X)        = T if X is a negative number of any type
                  = error if X is a non-numerical quantity
                  = NIL otherwise

(*GREAT X Y)      = T if X and Y are numbers of any type and X > Y.
                  = error if either X or Y is not a number
                  = NIL otherwise

(*LESS X Y)       = (*GREAT Y X)
```

```
(GREATERP X↓1 X↓2 ...X↓n)        = T if (*GREAT X↓1 X↓2) and
                                        (*GREAT X↓2 X↓3) and
                                        (*GREAT X↓n-1 X↓n)

                                 = error if any X↓i is a non-numerical
                                   quality
                                 = NIL otherwise

(LESSP X↓1 X↓2 ... X↓n)          = (GREATERP X↓n X↓n-1 ... X↓1)
```

Other numerical predicates may be defined as follows:

```
(DE FLOATP (X) (COND ((EQ X (PLUS X Ø))NIL)
                     ((EQ (CADR X) (QUOTE FLONUM)) T)
                     (T NIL)))
(DE FIXP (X) (NOT(FLOATP X)))
(DE ONEP (X) (ZEROP (DIFFERENCE X 1)))
(DE EVENP (X) (ZEROP (REMAINDER X 2)))
```

! 9.3 Boolean Predicates

The Boolean predicates perform logical operations on the truth values NIL and T. A non-NIL value is considered equal to T.

```
(NOT X) = T if X is NIL
        = NIL otherwise

(AND X↓1 X↓2 ...X↓n)     = T if all X↓i are non-NIL
                         = NIL otherwise
```

Note: (AND) = T. AND evaluates its arguments from left to right until either NIL is found in which case the remaining arguments are not evaluated, or until the last argument is evaluated.

```
(OR X↓1 X↓2 ... X↓n)     = T if any X↓i is non-NIL
                         = NIL otherwise
```

Note: (OR) = NIL. OR evaluates its arguments from left to right until either non-NIL is found in which case the remaining arguments are not evaluated, or until the last argument is evaluated.

CHAPTER 10

FUNCTIONS ON S-EXPRESSIONS

This chapter describes functions for building, fragmenting, oodifying, transforming, mapping, and searching S-expressions, as well as some non-standard functions on S-expressions.

! 10.1 S-Expression Building Functions

(CONS X Y)

The value of CONS of two S-expressions is the dotted pair of those S-expressions.

Example: (CONS (QUOTE A) (QUOTE B)) = (A.B)

Note: See Appendix D for information on functions associated with CONSing, such as SPEAK, GCGAG, and GC.

(XCONS X Y) = (CONS Y X)

(NCONS X) = (CONS X NIL)

(LIST X↓1 ... X↓n) = (CONS X↓1 (CONS X↓2 ...(CONS X↓n NIL)...))

List evaluates all of its arguments and returns a list of their values.

Examples:

```
(LIST) = NIL
(LIST (QUOTE A)) = A
(LIST (QUOTE A) (QUOTE B)) = (A B)
```

(*APPEND X Y)

```
(DE *APPEND (X Y)
     (COND ((NULL X) Y)
           (T (CONS (CAR X) (*APPEND (CDR X) Y)))))
```

(APPEND X↓1 X↓2 ...X↓n) = (*APPEND X↓1 (*APPEND X↓2 ...(*APPEND X↓n NIL)...)

Example:

```
(APPEND) = NIL
(APPEND (QUOTE (A B)) (QUOTE (C D)) (QUOTE (E))) = (A B C D
```

! 10.2 S-Expression Fragmenting Functions

(CAR L)

The CAR of a non-atomic S-expression is the first element of that dotted pair. CAR of an atom is undefined and will usually cause an illegal memory reference.

(CDR L)

The CDR of a non-atomic S-expression is the second (and last) element of that dotted pair. The CDR of an identifier is its property list. The CDR of an INUM causes an illegal memory reference. The CDR of any other number is the list structure representation of that number.

Examples:
```
(CAR (QUOTE (A B C))) = A
(CAR (QUOTE A)) is illegal
(CDR (QUOTE (A B C))) = (B C)
(CDR (QUOTE A)) is the property list of A
(CDR (QUOTE (A)))  = NIL
```

CAAR, CADR,..., CDDDDR

All of the composite CAR-CDR functions with up to four A's and D's are available.

Examples:
```
(CADR X) = (CAR (CDR X))
(CAADDR X) = (CAR (CAR (CDR (CDR X))))
```

(LAST L)

LAST returns the last part of a list according to the following definition:

```
(DE LAST (L)
    (COND ((ATOM (CDR L)) L)
          (T (LAST (CDR L)))))
```

Examples:
```
(LAST (QUOTE (A B C))) = (C) = (C.NIL)
(LAST (QUOTE (A B . C))) = (B.C)
```

* 10.3 S-Expression Modifying Functions

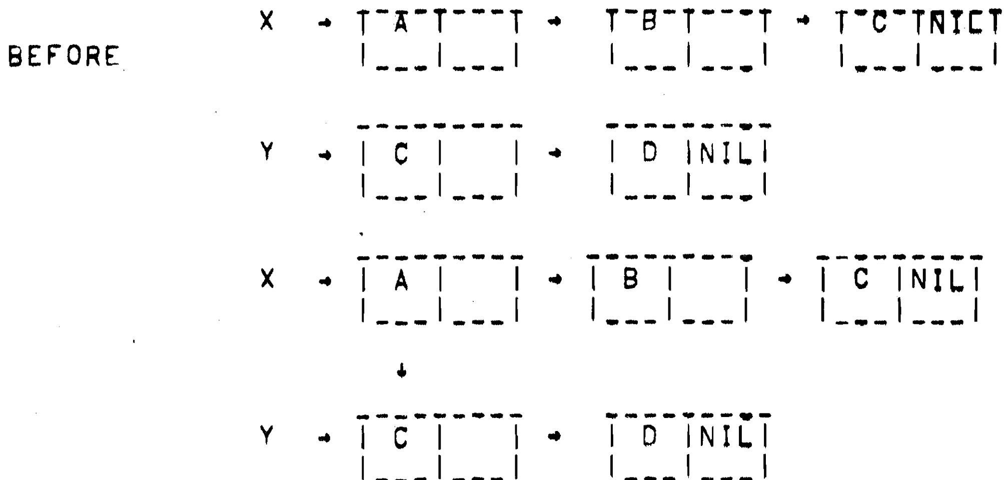
The following functions for manipulating S-expressions differ from all others in that they actually modify existing list structure rather than constructing new list structure. These functions should be used with caution since it is easy to create structures which will confuse or destroy the interpreter.

(RPLACA X Y)

Replaces the CAR of X by Y. The value of RPLACA is the modified S-expression X.

Example:
```
(RPLACA (QUOTE (A B C)) (QUOTE (C D))) = ((C D) B C)
```

Representation:



(RPLACD X Y)

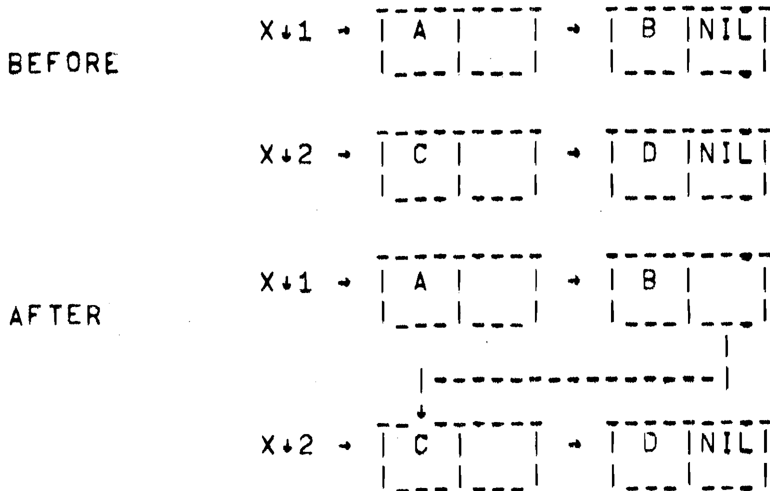
RPLACD replaces the CDR of X by Y. The value of RPLACD is the modified S-expression X.

(NCONC X↓1 X↓2 ... X↓n)

NCONC is similar in effect to APPEND, but NCONC does not copy nist structures. NCONC modifies list structures by replacing the nast element of X↓1 by a pointer to X↓2, the last element of X↓2 by a pointer to X↓3, etc. The value of NCONC is the modified list X↓1, which is the concatenation of X↓1, X↓2, ..., X↓n.

Examples: (NCONC) = NIL
(NCONC (QUOTE (A B)) (QUOTE (C D))) = (A B C D)

Representation:



10.4 S-Expression Transforming Functions

The following functions transform S-expressions from one form to another.

(LENGTH L)

LENGTH returns the number of top-level elements of the list L. LENGTH is equivalent to:

```
(DE LENGTH (L)
    (COND ((ATOM L) 0)
          (T (ADD1 (LENGTH (CDR L))))))
```

(REVERSE L)

REVERSE returns the reverse of the top level of list L. REVERSE is equivalent to:

```
(DE REVERSE (L) (REVERSE1 L NIL))
(DE REVERSE 1 (L M)
        (COND ((ATOM L) M)
              (T (REVERSE1 (CDR L) (CONS (CAR L) M)))))
```

(SUBST X Y S)

SUBST substitutes S-expression X for all EQUAL occurrences of S-expression Y in S-expression S. SUBST is equivalent to:

```
(DE SUBST (X Y S)
    (COND ((EQUAL Y S) X)
          ((ATOM S) S)
          (T (CONS (SUBST X Y (CAR S))
                   (SUBST X Y (CDR S))))))
```

Note: (SUBST 0 0 X) is useful for creating a copy of the list X.

Example: (SUBST 5 (QUOTE FIVE) (QUOTE (FIVE PLUS FIVE IS TEN)))
= (5 PLUS 5 IS TEN)

10.5 S-Expression Mapping Functions

The folnowing functions perform mappings of lists according vo the functional arguments supplied.

(MAP FN L)

MAP applies the function FN of one argument to list L and to successive CDRs of L until L is reduced to NIL. The value of MAP is NIL. MAP is equivalent to:

```
(DE MAP (FN L)
    (PROG NIL
     L1   (COND ((NULL L)(RETURN NIL)))
          (FN L)
          (SETQ L (CDR L))
          (GO L1)))
```

Example: (MAP (FUNCTION PRINT) (QUOTE (X Y Z))) =

```
PRINT:       (X Y Z)
PRINT:       (Y Z)
PRINT:       (Z)
PRINT:       NIL
```

(MAPC FN L)

MAPC is identical to MAP except that MAPC applies function FN vo the CAR of the remaining list at each step. MAPC is equivalent to:

```
(DE MAPC (FN L)
    (PROG NIL
    L1    (COND ((NULL L)(RETURN NIL)))
                (FN (CAR L))
                (SETQ L (CDR L))
                (GO L1)))
```

Example: (MAPC (FUNCTION PRINT) (QUOTE (X Y Z))) =

```
PRINT:       X
PRINT:       Y
PRINT:       Z
PRINT:       NIL
```

(MAPLIST FN L)

MAPLIST applies the function FN of one argument to list L and vo successive CDRs of L until L is reduced to NIL. The value of MAPLIST is the list of values returned by FN. MAPLIST is equivalent vo:

```
(DE MAPLIST (FN L)
    (COND ((NULL L) NIL)
    (T (CONS (FN L) (MAPLIST FN (CDR L))))))
```

Examples: (MAPLIST (FUNCTION CAR) (QUOTE (A B C D))) = (A B C D)
(MAPLIST (FUNCTION REVERSE) (QUOTE (A B C D))) =
((D C B A) (D C B) (D C) (D))

(MAPCAR FN L)

MAPCAR is identical to MAPLIST except that MAPCAR applies FN vo the CAR of the remaining list at each step. MAPCAR is equivalent vo:

```
(DE MAPCAR (FN L)
    (COND ((NULL L) NIL)
          (T (CONS (FN (CAR L)) (MAPCAR FN (CDR L))))))
```

```
Examples:      (MAPCAR (FUNCTION NCONS) (QUOTE (A B C D))) = ((A) (B) (C) (
               (MAPCAR (FUNCTION ATOM) (QUOTE ((X) Y (Z)))) = (NIL T NIL)
```

10.6 S-Expression Searching Functions

(ASSOC X L)

ASSOC searches the list of dotted pairs L for a pair whose CAR is EQ to X. If such a pair is found it is returned as the value of ASSOC, otherwise NIL is returned. ASSOC is equivalent to:

```
(DE ASSOC (X L)
    (COND ((NULL L) NIL)
          ((EQ X (CAAR L)) (CAR L))
          (T (ASSOC X (CDR L)))))
```

```
Example:       (ASSOC 1 (QUOTE ((1.ONE) (2.TWO)))) = (1.ONE)
```

(SASSOC X L FN)

SASSOC searches the list of dotted pairs L for a pair whose CAR is EQ to X. If such a pair is found it is returned as the value of ASSOC, otherwise the value of FN, a function of no arguments, is returned.

```
(DE SASSOC (X L FN)

    (COND ((NULL L) (FN))
          ((EQ X (CAAR L)) (CAR L))
          (T (SASSOC X (CDR L) FN))))
```

```
Example:       (SASSOC 0 (QUOTE ((1.ONE) (2.TWO)))
                         (FUNCTION (LAMBDA NIL (QUOTE LOSE)))) = LOSE
```

10.7 Character List Transforming Functions

(EXPLODE L)

EXPLODE transforms an S-expression into a list of single character identifiers identical to the sequence of characters which would be produced by PRINC.

```
Example:       (EXPLODEC (QUOTE (DX_/-_DY)))
               = (/(D X / _ / - / _ D Y/))
```

```
(FLATSIZE L)    = (LENGTH (EXPLODE L))
```

(MAKNUM L)

MAKNUM transforms a list of single character identifiers (actually takes the first character of each identifier) into an S-expression identical to that which would be produced by READing those characters. MAKNAM however does not INTERN any of the identifiers in the S-expression it produces.

```
Examples:        (MAKNUM (QUOTE (A P P L E))) = APPLE
                 (MAKNAM (QUOTE (//_/)))) = /)
```

(READLIST L)

READLIST is identical to MAKNAM except that READLIST INTERNs all identifiers in the S-expression it produces. READLIST is the nogical inverse of EXPLODE, i.e.,

```
                 (READLIST (EXPLODE L)) = L
                 (EXPLODE (READLIST L)) = L
```

CHAPTER 11

FUNCTIONS ON IDENTIFIERS

There are three basic types of functions on identifiers: those which manipulate their property lists, those which create new identifiers, and those which control their membership in the OBLIST.

NOTE: All functions described in this chapter which expect an identifier as one (or more) of its arguments will give either erroneous results, or an error condition if any S-expression other than an identifier is supplied.

11.1 Property List Functions

(GET I P)

GET is a function which searches the property list of the identifier I looking for the property name which is EQ to P. If such a property name is found, the value associated with it is returned as the value of GET, otherwise NIL is returned. Note that confusion exists if the property is found, but its value is NIL. GET is equivalent to:

```
(DE GET (I P) (COND ((NULL (CDR I)) NIL)
                    ((EQ (CADR I) P) (CADDR I))
                    (T (GET (CDDR I) P))))
```

(GETL I L)

GETL is another function which searches property lists. GETL searches the property list of the identifier I looking for the first property which is a member (MEMQ) of the list L. GETL returns the remaining property list, including the property name if any such property was found, NIL otherwise. GETL is equivalent to:

```
(DE GETL (I L) (COND ((NULL (CDR I)) NIL)
                     ((MEMQ (CADR I) L) (CDR I))
                     (T (GETL (CDDR I) L))))
```

(PUTPROP I V P)

PUTPROP is a function which enters the property name P with property value V into the property list of identifier I. If the property name P is already in the property list, the old property value is replaced by the new one; otherwise the new property name P and its value V are placed on the beginning of the property list. PUTPROP returns V.

(REMPROP I P)

REMPROP removes the property P from the property list of identifier I. REMPROP returns T if there was such a property, NIL otherwise.

SET and SETQ are used to change the values of variables which are bound by either LAMBDA or PROG, or variables which are bound globally. (See 7.1).

* (SET E V)

SET changes the value of the identifier specified by the expression E to V and returns to V. Both arguments are evaluated.

Note: In compiled functions, SET can be used only on globally bound and special variables.

! (SETQ "ID" V)

SETQ changes the value of ID to V and returns V. SETQ evaluates V, but does not evaluate ID.

(DEFPROP "I" "V" "P") = (PROG2 (PUTPROP (QUOTE I) (QUOTE V) (QUOTE P))(QUOTE I))

DEFPROP is the same as PUTPROP except that it does not evaluate its arguments, and DEFPROP returns I.

Example: (DEFPROP POSP (LAMBDA (X) (GREATERP X Ø)) EXPR)

(DE "ID" "ARGS" "BODY")

DE places the form (LAMBDA ARGS BODY) on the property list of ID under property EXPR. If ID previously had any of the properties EXPR, FEXPR, SUBR, FSUBR, LSUBR, or MACRO, then DE will return the nlst (ID REDEFINED). Otherwise, DE returns ID.

(DF "ID" "ARGS" "BODY")

Same as DE except defines a function with FEXPR property.

(DM "ID" "ARGS" "BODY")

Same as DE except defines a MACRO.

11.2 OBLIST Functions

(INTERN I)

INTERN puts the identifier I in the appropriate bucket of OBLIST. If the identifier is aready a member of the OBLIST, then INTERN returns a pointer to the identifier already there. Otherwise, INTERN returns I.

Note: INTERN is only necessary when an identifier which was created by
GENSYM, MAKNAM, or ASCII needs to be uniquely stored.

(REMOB "X↓1" "X↓2 ... "X↓n")

REMOB removes all of the identifiers X↓1, X↓2, ... , X↓n from the OBLIST and returns NIL. None of the X↓i's are evaluated.

Example: (REMOB FOO BAZ)

11.3 Identifier Creating Functions

The following functions create new identifiers but do not INTERN them onto the OBLIST.

(GENSYM)

GENSYM increments the generated symbol counter and returns a new identifier specified by the counter. The GENSYM counter is initialized to the identifier G0000. Successive executions of (GENSYM) will return.

G0001, G0002, G0003, ...

(CSYM "I")

CSYM initializes generated symbol counter to the identifier I, and returns I. CSYM does not evaluate its argument.

```
Example:        (CSYM ARY00)     = ARY00
                (GENSYM)         = ARY01
                (GENSYM)         = ARY02
                  etc.
```

(ASCII N)

ASCII creates a single character identifier whose ASCII print name equals N.

Example: (ASCII 101) is an identifier with print name "A".

CHAPTER 12

FUNCTIONS ON NUMBERS

There are two types of functions which operate on numbers to create new numbers: arithmetic and logical.

! 12.1 Arithmetic Functions

Unless otherwise noted, the following arithmetic functions are defined for both integer, real and mixed combinations of arguments, and evaluate all their arguments. The result is real if any argument is real, and integer if all arguments are integer. Most arithmetic functions may cause overflow which produces an error message.

```
(MINUS X)                  = -X

(*PLUS X Y)                = X + Y

(PLUS X1 X2 ... Xn)        = X1 + X2 + ... + Xn

(*DIF X Y)                 = X - Y

(DIFFERENCE X1 X2...Xn)    = X1 - X2 - ... -Xn

(*TIMES X Y)               = X * Y

(TIMES X1 X2 ... Xn)       = X1 * X2 * ... * Xn

(*QUO X Y)                 = X / Y

(QUOTIENT X1 X2 ...Xn)     = X1 / X2 / ... / Xn
```

For integer arguments, *QUO and QUOTIENT give the integer part of the real quotient of the arguments.

```
Examples:       (*QUO 5 2) = 2
                (*QUO -5 2) = -2
```

(REMAINDER X Y) ... X - (X / Y) * Y

Note: Remainder is not defined for real arguments.

(DIVIDE X Y) = (CONS (QUOTIENT X Y) (REMAINDER X Y))

(GCD X Y) GCD returns the greatest common divisor of the integers X and Y.

```
(ADD1 X)        = X + 1 (SUB1 X)        = X - 1
(ABS X)         = | X |
```

(FIX X) returns the largest integer not greater than X.

```
Examples:       (FIX 1) = 1
                (FIX 1.1) = 1
                (FIX -1.1) = -2          not -1
```

Other arithmetic functions not defined in the LISP interpreter can be defined as follows:

```
(FLOAT X) = (*PLUS X 0.0)

(RECIP X) = (QUOTIENT 1 X)

(SIGN X) = (COND ((ZEROP X) 0)
                ((MINUSP x) -1)
                (T 1))

(ROUND X) = (TIMES (SIGN X) (FIX (PLUS (ABS X) 0.5)))

Examples:       (ROUND .5) = 1
                (ROUND .49) = 0
                (ROUND -.49) = 0
                (ROUND -35.1) = -35

(MIN X Y) = (COND ((LESSP X Y) X) (Y))

(MAX X Y) = (COND ((LESSP X Y) Y) (X))

Examples:       (MINUS 1)                = -1
                (MINUS -1.2)             = 1.2
                (PLUS 1 2 3.1            = 6.1
                (PLUS 6 3 -2)            = 7
                (DIFFERENCE 6 3 1)       = 2
                (TIMES -2 2.0)           = -4.0
                (QUOTIENT 5 2)           = 2
                (QUOTIENT 5.0 2)         = 2.5
                (QUOTIENT -5 2) = 2
                (REMAINDER 5 2)          = 1
                (REMAINDER -5 2)         = -1
                (REMAINDER 5.0 2)        = undefined
                (ABS -32.5)              = 32.5
                (FIX 32.5)               = 32.
                (FIX -32.5)              = -33.
```

12.2 Logical Functions

The following functions are intended to operate on INUM and FIXNUM arguments, but their results are not defined for BIGNUM or FLONUM (real) arguments.

(BOOLE N X1 X2 ... Xn)

BOOLE causes a 36 bit Boolean operation to be performed on its arguments. The value of N specifies which of 16 Boolean operations to perform.

For n = 2, each bit_i in (BOOLE N A B) is defined:

N	result	N	result
0	0	10	$\bar{A}_i \wedge \bar{B}_i$
1	$A_i \wedge B_i$	11	$A_i \equiv B_i$
2	$\bar{A}_i \wedge B_i$	12	$\bar{A}_i$
3	B_i	13	$\bar{A}_i \vee B_i$
4	$\bar{A}_i \wedge B_i$	14	$\bar{B}_i$
5	A_i	15	$\bar{A}_i \vee B_i$
6	$A_i \neq B_i$	16	$\bar{A}_i \vee B_i$
7	$A_i \vee B_i$	17	1

For n > 2, BOOLE is defined:

```
(BOOLE N ... (BOOLE N (BOOLE N X1 X2) X3) ... Xn)
```

(LSH X N)

LSH performs a logical left shift of N places on X. If n is negative, X will be shifted right. In both cases, vacated bits are filled with zeros.

Examples with IBASE = 8

```
(BOOLE 1 76 133)        = 32
(BOOLE 1 76 133 70)     = 30
(BOOLE 12 13 0)         = 777777777764
(BOOLE 7 7 12)          = 17
(LSH 15 2)              = 64
(LSH 15 -2)             = 3
(LSH -1 -2)             = 177777777777
```

CHAPTER 13

PROGRAMS

The "program feature" allows one to write ALGOL-like sequences of statements with program variables and labels.

(PROG "VARLIST" "BODY")

PROG is a function which takes as arguments VARLIST, a list of program variables which are initialized to NIL when the PROG is entered (see 7.1), and a BODY which is a list of labels (which are identifiers) and statements which are non-atomic S-expressions. PROG evaluates its statements in sequence until either a RETURN or GO is evaluated, or the list of statements is exhausted, in which the value of PROG is NIL.

(RETURN X)

RETURN causes the PROG containing it to be exited with the value X.

(GO "ID")

GO causes the sequence of control within a PROG to be transferred to the next statement following the label ID. In interpreted PROGs, if ID is non-atomic, it is repeatedly evaluated until an atomic value is found. However, in compiled PROGs, ID is evaluated only once. GO cannot transfer into or out of a PROG.

Note: Both RETURN and GO should only occur either at the top level of a PROG, or in compositions of COND, AND, OR, and NOT which are at the top level of a PROG.

Example: The function LENGTH may be defined as follows:

```
(DE LENGTH (L)
(PROG (N)
        (SETQ N Ø)
L1 (COND ((ATOM L) (RETURN N)))
        (SETQ N (ADD1 N))
        (SETQ L (CDR L))
        (GO L1)))
```

(PROG2 X↓1 X↓2 ... X↓n) , n≤5.

PROG2 evaluates all expressions X↓1 X↓2 ... X↓n, and returns the value of X↓2.

CHAPTER 14

INPUT/OUTPUT

14.1 File Names

```
Syntax: <filename - list>      ::= <device-name>
                               ::= <filename-list><device-name>
                               ::= <filename-list><file - name>

        <device - name>        ::= <identifier> :
                               ::= (<atom><atom>)

        <filename>             ::= <identifier>
                               ::= (<identifier> . <identifier>)
```

Semantics:

A device-name is either an identifier ending with colon (:) which is the name of some input or output device, or a list containing a project-programmer number which implicitly specifies the disk.

A filename is either an identifier which specifies a filename with a blank extension, or a dotted pair of filename and extension. In both cases the filename applies to the most recently (to the left) specified device-name.

14.2 Channel Names

Channel names can optionally be assigned to files selected by the functions INPUT and OUTPUT. A channel name is any identifier which is not folnowed by a colon. If no channel name is specified to INPUT or OUTPUT then the channel name T is assumed. The channel name NIL specifies the teletype in the functions INC and OUTC. Up to 14 channels may be active at any time.

14.3 Input

14.3.1 Selection and Control

(INPUT "CHANNEL" . "FILENAME-LIST")

INPUT releases any file previously initialized on the channel, and initializes for input the first file specified by the filename-list. INPUT returns the channel if one was specified, T otherwise. INPUT does not evaluate its arguments.

(INC CHANNEL ACTION)

INC selects the specified channel for input. The channel NIL selects the teletype. If ACTION = NIL then the previously selected input file is not released, but only deselected. If ACTION = T then that file is released, making the previously selected channel

available. At the top level, ACTION need not be specified.

The input functions in 14.3.3 receive input from the selected input channel. When a file on the selected channel is exhausted, then the next file in the filename-list for the channel is initialized and input, until the filename-list is exhausted. Then the teletype is automatically selected for input and (ERR (QUOTE EOF)) is called. The use of ERRSET around any functions which accept input therefore makes it possible to detect end of file. If no ERRSET is used, control returns to the top level of LISP. INC evaluates its arguments, and returns the previously selected channel name.

In order to READ from multiple input sources, separate channels should be initialized by INPUT, and INC can then select the appropriate channel to READ from.

Example: The folnowing show a fairly typical sort of manipulation of two files at once.

```
 (LAMBDA (FILE)
  (PROG (CHAN1 CHAN2 EXPR1 EXPR2)
        (SETQ CHAN1 (INPUT  DSK: FOO)))) ;initialize FOO with channel name T
        (SETQ CHAN2 (EVAL (LIST @INPUT (GENSYM) @DSK: FILE)))
              ;this file is given a GENSYM channel name to prevent
              with any existing channels
   LOOP (INC CHAN1 NIL) ;select first channel
        (SETQ EXPR1 (READ))       ;read an expression from FOO
        (COND ((EQ EXPR1 (QUOTE *EOF*)) (GO EXIT1)))    ;end of first file?
        (SETQ EXPR1 (CAR EXPR1))          ;undo effect of ERRSET
        (INC CHAN2 NIL) ;open second channel
        (SETQ EXPR2 (ERRSET READ))        ;read an expression
        (COND ((EQ EXPR2 (QUOTE *EOF*)) (GO EXIT2))     ;end of this file?
              ((ATOM EXPR2) (GO ERROR)))          ;read error?
        (SETQ EXPR2 (CAR EXPR2))          ;undo effect of errset
              ..........................
              process in EXPR1 and EXPR2
              ..........................
              (GO LOOP)
   ERROR        ;error routine
   EXIT1        ;exit when first file ends first
   EXIT2        ;exit when sencond file ends first
              etc.
```

(DSKIN . "FILENAME-LIST")

In loading a file into a LISP program, it is not normally necessary to make use of the full generality available in INC and INPUT. The function DSKIN is supplied for this purpose. It has the same effect as doing INC and INPUT on its arguments, except that no channel name is admissible, and no device name is required. The

channel name will always be T, and 'DSK' will be supplied as a device name, if none is given.

Example:

(DSKIN FOO DTA3: BAR (1,JMC) (SIMU,MAN))

will READ the files FOO from DSK:, BAR from DTA3: and SIMU,MAN from the disk area [1,JMC].

When reading an input file, it is sometimes desirable to know the page and line being read from. PGLINE returns the dotted pair (page number , line number) for the selected input file. The page number is applicable only to STOPGAP files. If the file has no line numbers, PGLINE will always return (1 , 0).

14.3.2 Teletype Input Control

When input is from the teletype, READ is terminated by either an entire S-expression or by an incomplete S-expression followed by altmode. Altmode has the effect of typing a space followed by the appropriate number of right parens to complete the S-expression. This feature is particularly useful when an unknown number of right parens are needed or when in (DDTIN NIL) mode.

* (DDTIN X)

DDTIN is a function which selects teletype input mode. With (DDTIN NIL), and typing to READ, READCH, or TYI, a rubout will delete the last character typed, and control U (↑U) will delete the entire last line typed. Input is not seen by LISP until either altmode or carriage return is typed.

With (DDTIN T) and typing to READ, a rubout will delete the entire S-expression being read and start reading again.

Note: (DDTIN T) is not recommended when the time-sharing system is swapping, since the program is reactivated (and hence swapped into core) after every character typed.

14.3.3 Input Transfer

! (READ)

READ causes the next S-expression to be read from the selected input device, and returns the internal representation of the S-expression. READ uses INTERN to guarantee that references to the same identifier are EQ.

READ will accept any S-expression which conforms to the following syntax:

Syntax:

```
<readable S-expr>        ::= <atom>
                         ::= @<readable S-expr>
                         ::= (<readable S-exprlist>
                               {.<readableS-expr>})
                         ::= [<unbalanced S-expression list>]
                         ::= ( )           = NIL

<readable S-expr list>   ::= <readable S-expr>
                         ::= <readable S-expr><readable S-
                               expression list>
```

Semantics:

The delimiter "@" designates that the following readable S-expression is to be quoted.

```
Examples:     @A       means (QUOTE A)
              @(@A B)  means (QUOTE ((QUOTE A) B))
              @@A      means (QUOTE (QUOTE A)))
```

The delimiters "[" and "]" operate as "super-parentheses". A right bracket "]" will close all open left parentheses ")" up to the matching left bracket "[". If there is no matching left bracket, it will close the entire S-expression as does altmode. No syntax is given for unbalanced-S-expression-list, but it is intended to mean an S-expression-list which is lacking one or more right parentheses.

```
Example:      (COND [(ATOM X) (REVERSE(CDR Y][T(APPEND Y Z])
              (COND ((ATOM X) (REVERSE(CDR Y)))(T(APPEND Y Z)))
```

(READCH)

READCH causes the next character to be read from the selected input device and returns the corresponding single character identifier. READCH also uses INTERN.

(TYI)

TYI causes the next character to be read from the selected input device and returns the ASCII code for that character.

A function TEREAD which ignores all characters until a line-feed is seen can be defined:

```
(DE TEREAD NIL
(PROG NIL
L       (COND ((EQ (TYI) 12) (RETURN NIL)))
        (GO L)))
```

14.4 Output

14.4.1 Selection and Control

(OUTPUT "CHANNEL" , "FILENAME-LIST")

OUTPUT initializes for output on the specified channel the single file specified by the filename-list. OUTPUT does not evaluate its arguments, and returns the channel name if specified, T otherwise.

(OUTC CHANNEL ACTION)

OUTC selects the specified channel for output. The channel NIL selects the teletype. The output functions in 14.4.3 transfer output to the selected output channel.

If ACTION = NIL, then the previously selected output file is not closed, but only deselected. If ACTION = T then that file is closed, i.e., an end of file is written. OUTC evaluates its arguments and returns the previously selected channel name. At the vop level, ACTION need not be specified.

Examples: (At the top level)

```
(OUTC (OUTPUT LPT:) T)
(OUTC NIL T)
(OUTPUT FOO DSK: BAZ)
(OUTC (QUOTE FOO) NIL)
```

(LINELENGTH N)

LINELENGTH is used to examine or change the maximum output ninelength on the selected output channel. If N = NIL then the current linelength is returned unchanged, otherwise the linelength is changed to the value of N which is returned and must be an integer.

(CHRCT)

CHRCT returns the number of character positions remaining on the output line of the selected output channel.

When characters are output, if CHRCT is made negative, an ASCII 176 followed by a carriage-return and a line-feed are output. These characters are completely ignored on input. (See Chapter 3).

14.4.2 Output Transfer

! (PRIN1 S)

PRIN1 causes the S-expression S to be printed on the selected output device with no preceding or following spaces. PRIN1 also inserts slashes ("/") before any characters in identifiers which

would be syntactically incorrect otherwise (see Chapter 3). Double quotes around strings are printed.

(PRINC S)

PRINC is the same as PRIN1 except that no slashes are inserted and double quotes around strings are not printed.

(TERPRI X)

TERPRI prints a carriage-return and line-feed and returns the value of X. X may be omitted if the value of TERPRI is not used.

```
Example:        (PRINC(TERPRI X))
```

is the same as

```
                (PROG2 (TERPRI)(PRINC X))
```

! (PRINT S)

```
        = (PROG2 (TERPRI)
                 (PRIN1 S)
                 (PRINC (QUOTE/_)))
```

(TYO N)

TYO prints the character whose ASCII value is N, and returns N.

CHAPTER 15

ARRAYS

(ARRAY "ID" TYPE B↓1 B↓2 ... B↓n) n≤ 5.

ARRAY is a function which declares an array with name ID, and places an array referencing function on the property list of ID. TYPE determines the type of an array as follows:

TYPE	INITIAL VALUE	ARRAY ELEMENT
T	NIL	LISP S-expressions stored as pointers: 2 per word.
NIL	Ø.Ø	REAL numbers stored one per word in pDp-6/10 floating point representation.
36.	Ø	36 bit 2/s complement integers stored 1 per word.
Ø<n<36.	Ø	n bit positive integers packed [36./n] per word.

B↓1 B↓2 ... B↓n are array subscript bounds which should evaluate to either positive integers S↓I, or to dotted pairs of integers (L↓I . U↓I) where L↓I≤U↓I, which specify lower and upper subscript bounds as follows:

B↓I	LOWER BOUND	UPPER BOUND	LENGTH
S↓I	Ø	S↓I - 1	S↓I
(L↓I . U↓I)	L↓I	U↓I	U↓I-L↓I + 1

The elements of an array are referenced by:

(<array name> I↓1 I↓2 ... I↓n) where L↓J ≤ I↓J < U↓J.

The ARRAY subscripts I↓J must be integers. References to memory nocations outside of the area reserved for the array are prohibited and will cause an illegal memory reference message. Array elements are stored in BINARY PROGRAM SPACE.

Examples:

1) To declare a 1 dimensional array CHARS of 7 bit characters and with subscripts 1 to 5Ø:

```
(ARRAY CHARS 7 (QUOTE (1 . 5Ø)))
```

The first element of CHARS is referenced:

(CHARS 1)

2) To declare a 2-dimensional array A of REAL numbers and with subscripts Ø ≤ I < N, Ø ≤ J < M:

(ARRAY A NIL N M)

3) To declare a 1-dimensional array FOO of S-expressions and with subscripts -K ≤ I ≤ K:

(ARRAY FOO T (CONS (MINUS K) K))

*(EXARRAY "ID" TYPE B↓1 B↓2 ... B↓n) N ≤ 5.

EXARRAY is identical to ARRAY except that array elements are stored in the body of a subroutine loaded by the LOADER (see Appendix H), and exarray elements are not initialized. The array referencing subroutine is stored in BINARY PROGRAM SPACE as with ARRAY. EXARRAY searches symbol tables as does GETSYM (see Appendix H).

Note: Both ARRAY and EXARRAY consume BINARY PROGRAM SPACE. If there is insufficient room there (see Appendix C) the error message "BINARY PROGRAM SPACE EXCEEDED" will result.

(STORE ("ID" I↓1 I↓2 ... I↓n) value)

STORE changes the value of the specified array element to value, and returns value.

Note: STORE evaluates its second argument first.

Examples: With the arrays declared previously:

```
(STORE (FOO Ø) (QUOTE (A B)))
(STORE (FOO (BAZ L)) 1)
(STORE (A I J) (A J I))
(STORE (CHARS 1) 17)
```

15.1 Examine and Deposit

(EXAMINE N)

EXAMINE returns as an integer the contents of memory location N.

(DEPOSIT N V)

DEPOSIT stores the integer V in memory location N and returns V.

CHAPTER 16

OTHER FUNCTIONS

(TIME)

TIME returns the number of milliseconds your job has computed since you logged into the system.

(ERRSET E "F")

ERRSET evaluates the S-expression E and if no error occurs during its evaluation, ERRSET returns (LIST E). If an error occurs, then the error message will be suppressed if and only if F ≠ NIL, and NIL is returned as the value of ERRSET. If the function ERR is called during evaluation, then no message is printed and ERRSET returns the value returned by ERR.

The folnowing example shows the use of ERRSET to keep trying vo initialize the line printer until it is available:

```
(DE LPTGRAB NIL
(PROG NIL
L (COND ((ATOM(ERRSET (OUTPUT LPT:) T))
        (WAIT) (GO L)))))
```

where WAIT is some function (such as the time-sharing sleep UUO) which causes a delay.

(ERR E)

ERR returns the value of E to the most recent ERRSET, or to the top level of LISP if there is no ERRSET.

(*RSET X) flag = NIL initially

*RSET sets a special flag in the interpreter to the value of X, and returns the previous value of the flag. Normally, with (*RSET NIL), when an error occurs, special variables are restored to their top nevel values from the special pushdown list, and the top level READ-EVAL-PRINT loop is entered.

With (*RSET T), specials are not restored, neither pushdown nist is changed, and the READ-EVAL-PRINT loop is entered. This makes it possible to examine the variable bindings immediately after an error message has been printed. To restore special bindings to their vop level values and return to the top level, type a bell (*), or evaluate (ERR).

(BAKGAG X)

BAKGAG sets a special flag in the interpreter to the value of X and returns the previous setting of the flag. Only if the flag ≠ NIL when an error occurs, then a backtrace is printed as a series of function calls, determined from the regular pushdown list, starting from the most recent function call. If X is an integer, then X specifies the number of regular pushdown list words to include the backtrace. If X is T, then the entire regular pushdown list is backtraced to the most recent ERRSET. The format for printing is:

printout	meaning
fn1-fn2	Function 1 called function 2
fn1 - EVALARGS	The arguments to fn1 are being evaluated before entering function 1.
fn1 - ENTER	The function 1 is entered.
? - fn1	Some internal LISP function called function 1.

Note: The BACKTRACE printout is often confused by compiled function calls of the form (RETURN (FOO X)) which is compiled as (JCALL (E FOO)) which can be changed to (JRST entrance to FOO), which will not show up in the BACKTRACE.

(INITFN FN)

INITFN selects the function of no arguments FN as an initialization function which is evaluated after a LISP error return vo the top level has occurred or whenever a BELL is typed. INITFN returns the previously selected initialization function.

Initialization functions are useful when it is desirable to change the top level of LISP. For instance,

(INITFN (FUNCTION EVALQUOTE))

causes the top level to become EVALQUOTE instead of EVAL.

APPENDIX A

ALVINE

by John Allen

ALVINE is a LISP editor which is very convenient for interactive debugging. ALVINE allows one to edit both function definitions and S-expression values. ALVINE is characterized by the simplicity with which one can correct a parenthesis mismatch and make context searches and replacements. This simplicity arises from the data structure ALVINE uses to represent an S-expression. All S-expressions are flattened into a list of atoms including the atoms %LP, %RP and %D which represent "(", ")" and ".". Because of this representation, ALVINE looks more like a string type text editor with the smallest unit of resolution being a single atom or S-expression delimiter (%LP %RP or %D).

ALVINE has a pointer which can move through the string being edited. The editing functions affect only the string to the right of the pointer.

ALVINE also contains functions for manipulating input-output files, and GRINDEF which is useful for printing function definitions.

ALVINE is not ordinarily a resident part of the LISP system, but is automatically loaded whenever the function ED is called.

(ED X)

ED loads ALVINE if it is not already loaded. If X = NIL then the editor is entered. If X = T, the editor is not entered. This is useful to load GRINDEF without entering the editor.

From the top level of LISP, (ED) is the same as (ED NIL).

(SPRINT X Y 1)

SPRINT prints S-expression X in a special format which automatically indents according to parenthesis level. Whenever any sub-S-expression of X cannot fit entirely on the same printing line, vhen its sub-S-expressions are printed on separate lines with matching indentation. The parameter Y specifies the initial left hand column indentation. SPRINT uses CHRCT and LINELENGTH to determine the number of characters remaining on the print line.

(GRINDEF "F1" "F2" ... "Fn")

GRINDEF is used to print the definitions of functions and values in DEFPROP format. GRINDEF uses SPRINT to print function definitions in a highly readable format. GRINDEF prints all

properties of the identifiers F1, F2, ... Fn which are in the list %%%L which is initialized to EXPR, FEXPR, VALUE, MACRO and SPECIAL.

Example: (GRINDEF PLUS)

```
(DEFPROP PLUS
 (LAMBDA (L) (*EXPAND L (QUOTE *PLUS)))

MACRO)
```

Description of the Command Structure

Each command to ALVINE consists of a single character (possibly preceded by a number) followed by a string of arguments. These commands modify the text string presently occupying ALVINE's buffer. When text is introduced to ALVINE a pointer is attached preceding the first object in the buffer. ALVINE's commands allow the user to move this pointer through the buffer. ALVINE's text modifying commands only affect the string to the right of this pointer.

In the following command descriptions, "pointer string" will mean the string to the right of the pointer, and "$" will mean an altmode. All of the commands which allow a repetition argument n assume 1 if n is omitted.

COMMAND	MEANING	DESCRIPTION
A	All	Print the buffer string. No attempt is made to make the output pretty.
B	Balanced?	Examines the number of parens in the buffer string. Returns the count of left and right parens if unbalanced; otherwise replies "BAL".
nC	Count	For readability, the commands "D", "M", ">", "<", "S", and "W", will print an initial segment of the pointer buffer. "nC" sets the length of this printing segment to n objects.
nD	Delete	Deletes the first n "objects" to the right of the pointer.
nE	Expunge	Deletes the first n S-expressions to the right of the pointer.

F x y:z	File	GRINDEFS the identifiers referred to by x on device y using file name z. If X is a list of identifie then each element of x is GRINDEFed If x is an atom, then the value of x is used as a list of atoms to GRINDEF.
Gx	Get	G will convert an S-expression with name x into ALVINE form, move it into the ALVINE buffer and initialize the pointer to the left hand end of the buffer. GET looks on the property list of x for the first property in the list %%%L which is initialized to (FEXPR EXPR VALUE MACRO SPECIAL). %%%L may be SETQed globally as desired. G also knows about TRACEd functions and will handle them properly. ALVINE format was described earlier as a single level list of atoms including the special atoms %LP, %RP, %D.
I	Insert	Insert comes in two flavors: 1. Ix: Insert "x" immediately to the right of the pointer. 2. Ixy: Insert "y" after the first occurrence (in the pointer string) of the string "x". "x" may be a complete string or described by ellipsis as "w...z" If "x" is % then "y" is introduc to the editor as the current string.
nM	Match	Move the pointer n S-expressions to the right of the current pointer position. If n is negative, move n S-expressions left. If there is no such S-expression the pointer is not moved and the bell is sounded.
Px	Put	Converts the editor string from ALVINE format to an S-expression and puts it back on the property list of x with the appropriate property.

Qx	<follows P>	Same as P except no function name need be specified. Q puts the S-expression in the editor buffer back on the property list of the identifier the last G specified.
Rxy	Replace	Replace the first occurrence of "x" by "y". As with "I", "x" may be described elliptically; and if "y" is %, the first occurrence of "x" is deleted.
nSx$	Search	Search for the nth occurrence of the string "x" (in the pointer string). If found, the pointer is moved to the beginning of the string following that occurrence. If less than n occurrences are located, the pointer is positioned after the last such occurrence. If none are found the pointer is not moved. If "x" is not given, i.e., "nS$", then the last given search-string is used.
Uxy:z	Unfile	READs and defines the functions specified by the list x from device y using z as a file name. If x is an atom, then the value of x is used as a list function names to READ. U prints the names of the functions as it defines them. The specified file must be in GRINDEF format.
V	Vomit	Print the first balanced paren section to the right of the point in pseudo GRINDEF format.
W	Where?	Prints the beginning of the pointer string.
n> and n<		These commands are dual; they move the string pointer "n" objects to the right or left respectively. If "n" is such that either the left or right end of the string would be exceeded, the pointer is set to that extreme and "bell" is typed. To reset to the extreme left of the string "Ø<" may be used.

This command returns control to LISP. ALVINE's buffer is left intact, and returning to ALVINE, the user will find the pointer at the left hand end of the old string.

Bell — Bell may be used during any command to return control to ALVINE's command-listen-loop.

AN EXAMPLE OF ALVINE

Note: Bell, space and alt-mode are represented by *, _ and $ respectively.

```
(ED)

*
I % $(DEFPROP TEST (LAMBDA $;  the string bounded by "$" is introduced to
        ALVINE

*
A$
(DEFPROP TEST (LAMBDA ; print the entire ALVINE buffer
*
B$
2LPS
Ø RPS
*
I LAMBDA $ (X) (CAR Y) EXPR) $;  append the string bounded by "$" to the
        buffer

*
B$
4LPS
3 RPS
*
I CAR Y $)$ ;  add the deficient right paren

                                        ;  the following commands
                                           would also have the same
                                        ;  1.  "11<", "I $)$"
                                        ;  2.  "SY$", I $)$
B$
BAL ;
$
V$
(DEFPROP TEST (LAMBDA (X) (CAR Y))EXPR)
*
P TEST$; convert ALVINE string to LISP function
*
↑ ; exit ALVINE
```

```
TS;  now talking to LISP
T
(TEST (QUOTE(A B)))
Y
UNBOUND VARIABLE-EVAL ; LOSE
(ED)    ; re-enter ALVINE.
*
W$
(DEFPROP TEST; "G" need not be executed since the buffer is always left inta
*
R X $ Y$
*
P TS* ; flush incorrect "put" command by typing bell. (*)
*
PTEST $ ; redefine TEST
*
*
(TEST (QUOTE(A B)))$ ; try again
A                    ; win
(ED)
*
5 > $
(Y)
*
5C $ ; change print count
*
M $
(CAR Y))
*
E $
*
A $
(DEFPROP TEST (LAMBDA (Y))EXPR)
*
W $
)EXPR)
*
Ø < $
*(DEFPROP TEST(
*
R TEST ...) $%$
*
A $
(DEFPROP)EXPR) ; same effect by:
                 1. "SDEFPROP $", "6D"
*
```

APPENDIX B

ERROR MESSAGES

The LISP interpreter checks for some error conditions and prints messages accordingly. Many erroneous conditions are not tested and result in either the wrong error message at some later time, or no error message at all. In the latter case the system has screwed you (or itself) without complaining.

When error messages are printed, it is usually difficult to determine the function which caused the error and the functions which called it. In this situation, (BAKGAG T) will turn on the BACKTRACE flag which causes the heirarchy of function calls to be printed as described in the next section.

The following is an alphabetical listing of error messages, their cause, and in some cases, their remedy. Some error messages print two lines, such as:

FOO
UNBOUND VARIABLE - EVAL

These messages are described last in the listing, and are of the form:

X <message>

BINARY PROGRAM SPACE EXCEEDED

ARRAY, EXARRAY, or LAP has exceeded BINARY PROGRAM SPACE. ALLOCATE more BPS next time.

CAN'T EXPAND CORE

INPUT, OUTPUT, LOAD, or ED failed to expand core. Your job is too large.

CAN'T FIND FILE - INPUT

The input file was not found. You probably forgot to give the file name extension, or a legal name list.

DEVICE NOT AVAILABLE

INPUT or OUTPUT found the specified device unavailable. Some other job is probably using it.

DIRECTORY FULL

The directory of the output device is full.

DOT CONTEXT ERROR

READ does not like dots adjacent to parens or other dots.

FILE IS WRITE-PROTECTED

OUTPUT found that the specified file is write-protected.

FIRST ARGUMENT NON-ATOMIC - PUTPROP

An attempt was made to PUTPROP onto a non-identifier.

GARBAGED OBLIST

Some member of the OBLIST has been garbaged. You are in trouble.

ILLEGAL DEVICE

INPUT or OUTPUT was attempted to either a non-existent device or to a device of the wrong type. I.e., INPUT from the lineprinter.

ILLEGAL OBJECT - READ

READ objects to syntactically incorrect S-expressions.

INPUT ERROR

Bad data was read from the selected device.

MORE THAN ONE S-EXPRESSION - MAKNAM

MAKNAM and READLIST object to a list which constitutes the characters for more than one S-expression.

NO FREE STG LEFT

All free storage is bound to the OBLIST and protected cells (such as list ARRAY cells), and bound variables on either the REGULAR or SPECIAL pushdown list. Unbinding to the top level will usually release the storage. If you are in a bind for more free storage, try to REALLOC as described in APPENDIX C.

NO FULL WORDS LEFT

All full words are being used for print names and numbers. The problem and its solution are similar to FREE STG.

NO I/O CHANNELS LEFT

INPUT or OUTPUT failed to find a free I/O channel. There is a maximum of 14 active I/O channels.

NO INPUT - INC

n attempt was made to select a channel for input with INC which was not initialized with INPUT.

NO LIST - MAKNAM

MAKNAM and READLIST object to an empty list.

NO OUTPUT - OUTC

An attempt was made to select a channel for output with OUTC which was not initialized with OUTPUT.

NO PRINT NAME - INTERN

INTERN found a member of the OBLIST which has no print name. You are in trouble.

OUTPUT ERROR

Data was improperly written on the selected output device. Possibly a write-locked DECTAPE.

OVERFLOW

Some arithmetic function caused overflow - either fixed or floating.

PDL OVERFLOW FROM GC - CAN'T CONTINUE

There is not enough regular pushdown list to finish garbage collection. You lose. Try to REALLOC as described in APPENDIX C.

READ UNHAPPY - MAKNAM

MAKNAM and READLIST object to a list which is not an entire S-expression.

REG PUSHDOWN CAPACITY EXCEEDED SPEC PUSHDOWN CAPACITY EXCEEDED

A pushdown list has overflowed. This is usually caused by non-termination of recursion. Sometimes you need to ALLOCATE or REALLOC more pushdown list.

TOO FEW ARGUMENTS SUPPLIED - APPLY TOO MANY ARGUMENTS SUPPLIED - APPLY

APPLY checks all calls on interpreted functions for the proper number of arguments.

X MADE ILLEGAL MEMORY REFERENCE

The function X referred to an illegal address. Usually caused by taking the CAR or CDR of an atom or number.

X NON-NUMERIC ARGUMENT

Arithmetic functions require that their arguments be numbers.

X PROGRAM TRAPPED FROM

An illegal instruction was executed in function X.

X UNBOUND VARIABLE - EVAL

EVAL tried to evaluate an identifier and found that it had no value. You probably forgot to QUOTE some atom to initialize it.

X UNDEFINED COMPUTED GO TAG IN

A GO in some compiled function had an undefined label.

X UNDEFINED FUNCTION X UNDEFINED FUNCTION - APPLY

The function X is not defined.

X UNDEFINED PROG TAG - GO

A GO in some interpreted function had an undefined label.

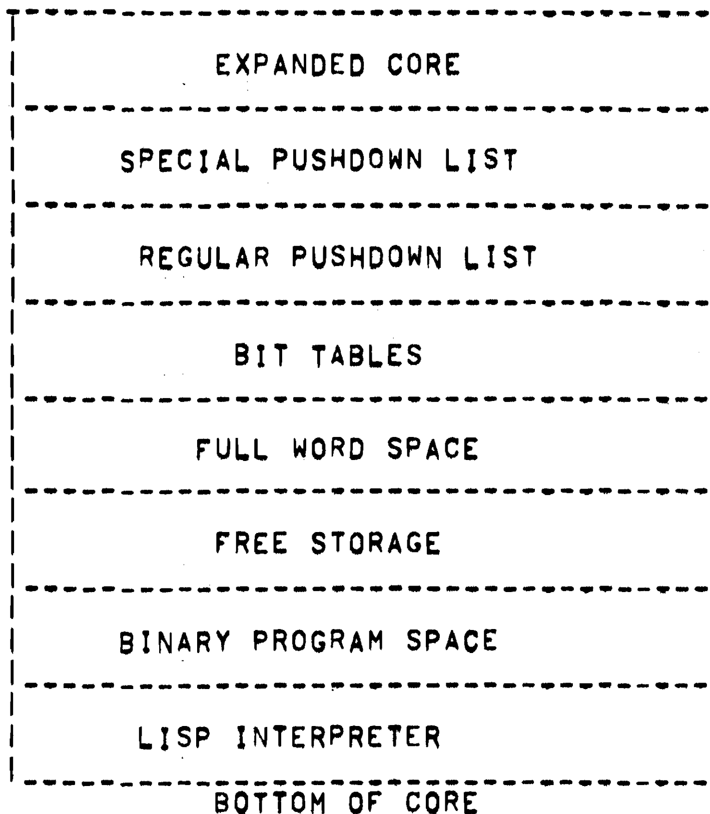
APPENDIX C

MEMORY ALLOCATION

The LISP 1.6 system has many different areas of memory for storing data which can independently vary in size. Some LISP applications demand larger allocations for these areas than others. To allow users to adjust the sizes of these areas to their own needs, a memory allocation procedure exists.

C.1 Summary of Storage Allocation Areas

BINARY PROGRAM SPACE	Area for compiled functions and arrays.
FREE STORAGE	Area for LISP nodes.
FULL WORD SPACE	Area for print names and numbers.
BIT TABLES	Area for the garbage collector.
REGULAR PUSHDOWN LIST	Area for all function calls and non-special variables in compiled functions.
SPECIAL PUSHDOWN LIST	Area for interpreted variables and special variables.
EXPANDED CORE	Area for I/O buffers, ALVINE, LOADER, and any loaded programs.



Memory map for the LISP 1.6 system

C.2 ALLOCATION

When the LISP system is initially started, it asks the user vo specify the size of each of its various spaces as follows.

```
FREE STORAGE = 10000 =
FULL WORDS = one fourth of free storage =
BIN. PROG. SP. = 2000 =
REG. PDL = 1000 + one sixteenth of free storage =
SPEC. PDL = 1000 + one sixteenth of free storage =
OBLIST SIZE = 177 =
```

The number given in between the equal signs is the default size which LISP will use if no number is supplied. As shown above, for some spaces it will vary with the sizes of others.

There are three basic responses to any of these questions:

1) A carriage return will cause the default value to be used.
2) A number followed by a carriage return will produce a space of that size.
3) An altmode in place of a carriage return will result in the remainder of the questions being skipped and the allocation procedure being ended.

C.3 REALLOC

If you have an existing LISP core image but have exhausted one of the storage areas, it is possible to increase the size of that area using the reallocation procedure. First, expand core with the vime sharing system command CORE and then re-enter the LISP core image with the START command. For example, if the original core size was 20K, you could increase it by 4K as follows:

```
↑C
.CORE 24
.START
*
```

When you reallocate a core image, all additional core is allocated as follows:

1/4 for full word space
1/64 for each pushdown list,
the remainder to free storage and bit tables.

C.4 Binary Program Space

The reallocation procedure does not increase the size of binary program space. However, it is possible to increase binary program space by expanding core with the CORE (C) command and setting BPORG and BPEND to the beginning and end of the expanded area of core. For example, if you now have 32K of core and want 4K more BPS, fo the following:

```
(EXCISE)          to eliminate IO buffers
↑C
.CORE 36
.START
*(SETQ BPORG (TIMES 32. 1024.))
*(SETQ BPEND (PLUS BPORG 4095.))
```

Note: If you use the reallocation procedure after having expanded core for any purpose, it will reallocate this additional core for its own purposes, thus destroying the contents of the expanded core.

The following are the standard causes for expansion of core:

1) using I/O channels.
2) using the LOADER -(LOAD).
3) expanding core for more binary program space.
4) using (ED).

APPENDIX D

GARBAGE COLLECTION

All LISP systems have a function known as the garbage collector. This function analyzes the entire state of list structure which is pointed to by either the OBLIST, the regular pushdown list, the special pushdown list, list arrays, and a few other special cells. By recursively marking all words on free and full word spaces which are pointed to in this manner, it is possible to determine which words are not pointed to and are therefore garbage. Such words are collected together on their respective free storage nists.

(GC)

GC causes a garbage collection to occur and returns NIL. Normally, a garbage collection occurs only when either free or full word space has been exhausted.

(GCGAG X)   flag = NIL initially.

GCGAG sets a special flag in the interpreter to the value of X, and returns the previous setting of the flag. When any garbage collection occurs, if the flag ≠ NIL, then the following is printed:

```
either          FREE STORAGE EXHAUSTED
    or          FULL WORD SPACE EXHAUSTED
    or          nothing

followed by     x FREE STORAGE, y FULL WORDS AVAILABLE
```

where x and y are numbers in octal.

(SPEAK)

SPEAK returns the total number of CONSes which have been executed in this LISP core image.

(GCTIME)

GCTIME returns the number of milliseconds LISP has spent garbage collecting in this core image.

It is possible to determine the lengths of the free and full word free storage lists by:

```
(LENGTH (NUMVAL 15↓8))  = length of free storage list
(LENGTH (NUMVAL 16↓8))  = length of full word list
```

APPENDIX E

COMPILED FUNCTION LINKAGE AND ACCUMULATOR USAGE

This appendix is intended to explain the structure of compiled functions, function calls, and accumulator usage. This discussion is relevant only if one intends to interface hand coded functions or possibly functions generated by another system (such as FORTRAN) with the LISP system. In such a case, it is highly recommended that one examine the LAP code generated by the LISP compiler for some familiar functions.

ACCUMULATOR USAGE TABLE

s means "sacred" to the interpreter

p means "protected" during garbage collection

NIL	= 0	s,p	Header for the atom NIL.
A	= 1	p	Results from functions, 1st arg to functions
B	= 2	p	2nd arg
C	= 3	p	3rd arg
AR1	= 4	p	4th arg
AR2A	= 5	p	5th arg
T	= 6	p	used for LSUBR linkage
TT	= 7	p	
T10	= 10	p	rarely used in the interpreter
S	= 11		rarely used in the interpreter
D	= 12		
R	= 13		
P	= 14	s,p	regular pushdown list pointer
F	= 15	s,p	free storage list pointer
FF	= 16	s,p	full word list pointer
SP	= 17	s,p	special pushdown list pointer.

TEMPORARY STORAGE

Whenever a LISP function is called from a compiled function, it is assumed that all accumulators from 2 through 13 are destroyed by the function unless it is otherwise known. Therefore, local variables and parameters in a compiled function should be saved in some protected cells such as the regular pushdown list. The PUSH and POP instructions are convenient for this purpose.

SPECIAL VARIABLE BINDINGS

Special variables in compiled functions are bound to special cells by:

```
PUSHJ P, SPECBIND
0 n↓1, var↓1
0 n↓2, var↓2
 ...
start of function code.
```

SPECBIND saves the previous values of var↓i on the special pushdown nist and binds the contents of accumulator n↓i to each var↓i. The var↓i must be pointers to special cells of identifiers. Any n↓i=0 causes the var↓i to be bound to NIL.

Special variables are restored to their previous values by:

```
PUSHJ P,SPECSTR
```

which stores the values previously saved on the special pushdown list in the appropriate special cells.

NUMBERS

To convert the number in A from its LISP representation to machine representation use:

```
PUSHJ P,NUMVAL
```

which returns the value of the number in A, and its type (either FIXNUM or FLONUM) in B.

To convert the number in A from its machine representation to LISP representation use either:

```
      PUSHJ P,FIX1A        for FIXNUMS
or    PUSHJ P,MAKNUM       with type in B.
```

Both of the above functions return the LISP number in A.

FUNCTION CALLING UUOS

To allow ease in linking, debugging, and modifying of compiled functions, all compiled functions call other functions with special opcodes called UUOs. Several categories of function calls are distinguished:

1) Calls of the form (RETURN (FOO X)) are called terminal calls and essentially "jump" to FOO.

2) Calls of the form (F X) where F is a computed function name or functional argument is called a functional call.

The function calling UUOS are:

	non-terminal	terminal

non-functional	CALL n,f	JCALL n,f
functional	CALLF n,f	JCALLF n,f

where f is either the address of a compiled function or a pointer to vhe identifier for the function, and n specifies the type of function being called as follows:

n = Ø to 5	specifies a SUBR call with n arguments
n = 16	specifies a LSUBR call
n = 17	specifies a FSUBR call.

The function calling UUOs are defined in MACRO by:

```
OPDEF CALL [34B8]
OpDEF JCALL [35B8]
OPDEF CALLF [36B8]
OPDEF JCALLF [37B8]
```

(NOUUO X)   flag = T initially

NOUUO sets a special flag in the compiled function calling mechanism to the value of X and returns the previous setting of the flag. Compiled functions initially call other functions with function calling UUOs which "trap" into the UUO mechanism of the interpreter. Ordinarily, such function calls involve searching the property list of the function being called for the functional property, and then (depending on whether the function is compiled or an S-expression) the function is called.

If the NOUUO flag is set to NIL, then the overhead in calling a compiled function from a compiled function can be eliminated by replacing the CALL by PUSHJ and JCALL by JRST. CALLF and JCALLF are never changed.

However, there are several dangers and restrictions when using (NOUUO NIL). Once the UUO's have been replaced by PUSHJ's then it is not possible to redefine or TRACE the function being called. It is therefore recommended that compiled functions be debugged with (NOUUO T).

SUBR LINKAGE

SUBRs are compiled EXPRs which are the most common type of function. Consequently, considerable effort has been made to make ninkage to SUBRs efficient.

Arguments to SUBRs are supplied in accumulators 1 through n, the first argument in 1. There is a maximum of 5 arguments to SUBRs.

To call a SUBR from compiled code, use call n,FUNC, where n is the number of arguments, and call is the appropriate UUO.

The result from a SUBR is returned in A(= 1).

FSUBR LINKAGE

FSUBRs receive one argument in A and return their result in A. FSUBRs which use the A-LIST feature call:

```
PUSHJ P, *AMAKE
```

which generates in B a number encoding the state of the special pushdown pointer. To call a FSUBR, use call 17, FUNC, here call is the appropriate UUO.

LSUBR LINKAGE

LSUBRs are similar to SUBRs except that they allow an arbitrary number of arguments to be passed. To call a LSUBR, the following sequence is used:

```
        PUSH P, [ret]    ;return address
        PUSH P, arg1     ;1st argument
          ...
        PUSH P, argn     ;nth and last argument
        MOVNI T,n        ;minus number of arguments
        call 16,func     ;the appropriate UUO
ret:                     ;the LSUBR returns here
```

When a LSUBR is entered, it executes:

```
JSP 3,*LCALL
```

which initializes the LSUBR. A will contain n. The ith argument can be referenced by:

```
MOVE A, -i-1(P)
```

Exit from an LSUBR with

```
POPJ P,
```

which returns to *LCALL to restore the stack.

APPENDIX F

THE LISP COMPILER

by Whitfield Diffie

The LISP compiler is a LISP program which transforms LISP functions defined by S-expressions into LAP assembly code. This can be loaded into binary program space by LAP (LISP Assembly Program), a combined assembler and loader, which produces absolute machine code in core.

Compiled functions are approximately twenty times as fast as interpreted functions. Compiled functions also take up less memory space and relieve the garbage collector from marking function definitions. In a very large system of functions, this last point is particularly significant.

The LISP compiler exists as the system program COMPLR, and is called by the incantation 'R COMPLR.' Once started, it is spoken to in the same dialect as any other LISP.

USE OF THE COMPILER

(COMPL . "FILENAME - LIST")

The function COMPL takes as arguments an assortment of file names and device names in precisely the same way as the function DSKIN. The default device to be used for input in the event that none is supplied in the argument sequence is given by the value of vhe variable INDEV. There is no provision for specification of an output device in the argument sequence. If the output is wanted on some device other than the user's disk area, the variable OUTDEV must be set to indicate this desire. All error messages and comments are normally directed to the teletype. They can be sent to some other device by setting the variable LISTING. Files produced by the compiler have the filename extension LAP.

Examples:

(COMPL FOO SYS: TRACE)

will compile the file FOO from the users disk area and the file TRACE from the system area to produce

the files FOO.LAP and TRACE.LAP on the users disk area.

```
(SETQ INDEV (QUOTE DTA2:)) (SETQ OUTDEV (QUOTE (2,DAV)))
(SETQ LISTING (QUOTE (DSK: CMPMSG)))
(COMPL HAT SYS: SMILE)
```

will compile the file HAT from DTA2: and the file SMILE from SYS: to produce the files HAT.LAP and SMILE.LAP on the disk area [2,DAV]. All compiler messages will appear as the file CMPMSG on the user's disk area.

PREPARING FILES FOR COMPILATION

In preparing a file for compilation there are several things that the user is well advised to bear in mind.

1) All normal function defining functions are acceptable to the compiler. Functions defined by DE, DF, and DEFPROP, and macros defined by DEFPROP or DM, will be correctly understood.

2) Any function which is unknown to the compiler when it is first obliged to generate a call thereto, will be assumed to be an EXPR or SUBR. If a file contains a function of any other type which is called by a function defined earlier in the file, it must be declared vo the compiler with one of the statements: (DEFPROP fun T *FSUBR) or (DEFPROP fun T *LSUBR) so that the compiler will know how to set up its arguments.

3) Any variable which occurs free in any function must be declared SPECIAL prior to the definition of any function which binds it. This may be done with a statement of the form '(DEFPROP var T SPECIAL).'

4) As macros are functions which are actually executed at compile time, their definitions must occur earlier in the file than any function which appeals to them. If this is not done, the macro will be mistaken for an undefined EXPR.

COMPILER MESSAGES

As the compiler goes about its business, it will make various comments and complaints about your code.

1) As the compilation of each function is completed, its name will be vyped on the teletype without carriage return. Any other message will be stood off by carriage returns above and below.

2) Whenever the compiler discovers a free variable which has not been declared special, it declares it. At the end of any function in which it found such variables it will print out the message:

(SPECIAL var1 var2 etc.).

3) If a prog variable is unused in a function the compiler will print the message (UNUSEDPROGVAR varname). It will also declare the variable special on the theory that if it was not used there, it must have been used somewhere else.

4) Many minor errors in user code will unfortunately go undetected. Any serious error will produce the message *USER ERROR* followed by a description of what was wrong. This will halt the compiler.

5) The error message *COMPILER ERROR* indicates a bug in the compiler. Please report this to Whitfield Diffie.

6) When the compiler has finished, it will type out the name of the file, the number of words of code produced and the time taken. Following these will be lists of any functions called but not defined in the file and any auxiliary functions the compiler generated.

USING COMPILED CODE

As LAP is self loading, the loading of compiled files is the same as for interpreted functions. The allocations must be changed, however, to reflect the passage of the code from free storage to binary program space. The correct size of the latter is the size of the program as stated at the end of compilation, plus the length of lap which is about 500(8) words.

The folnowing example illustrates various aspects of the compiler's behavior. We show a collection of functions, the LAP code generated from it, and the comments made by the compiler in the process.

THE FUNCTIONS

```
(DM FIRST (L) (CONS @ CAR (CDR L))) ;macro defined at beginning

(DEFPROP IT T SPECIAL)            ;special declaration

(DEFPROP MAPCONS                  ;the internal lambda
 (LAMBDA (IT LIST)                ;becomes a separate function
  (MAPCAR (FUNCTION               ;thus the variable IT must
           (LAMBDA (X)            ;  be made special
                   (CONS IT X)))
          LIST))
 EXPR)

(DEFPROP COUNTM
 (LAMBDA (SEXPR)
  (PROG (COUNT)                   ;the variable COUNT has not been
        (SETQ COUNT 0)            ;declared special and will be treated
        (COUNT1 SEXPR)            ;as local
        (RETURN COUNT)))
 EXPR)

(DE COUNT1 (SS)
 (COND ((ATOM SS) NIL)
       (T (INCR COUNT)            ;here it is discovered to be special
          (COUNT1 (FIRST SS))     ;but too late
```

```
          (COUNT1 (CDR SS)))))

(DE SCALE (NO)              ;this variable is found to
 (TIMES NO SCALEF))         ;be special, in good time

(DF SETQQ (L) (SET (CAR L) (CADR L)))

(SETQ SCALEF 3)             ;this will be output unchanged
```

THE RESULTING LAP

```
;note that the macro definition and the special declaration have
;been gobbled up by the compiler.

(LAP MAPCONSG0220 SUBR)          ;this is the function
        (MOVE 2 (SPECIAL IT))    ;generated by the
        (JCALL 2 (E XCONS))      ;internal lambda
        NIL                      ;in MAPCONS

(LAP MAPCONS SUBR)
        (JSP 6 SPECBIND)
        (0 2 (SPECIAL IT))
        (MOVEI 1 (QUOTE MAPCONSG0220))
        (CALL 2 (E MAPCAR))
        (JRST 0 SPECSTR)
        NIL

(LAP COUNTM SUBR)
        (PUSH P 1)       ;this code is in error
        (PUSH P (C 0 0 (QUOTE 0) 0))     ;due to the failure
        (CALL 1 (E COUNT1))              ;to make COUNT special
        (MOVE 1 0 P)
        (SUB P (C 0 0 2 2))
        (POPJ P)
        NIL

(LAP COUNT1 SUBR)
        (PUSH P 1)
        (CALL 1 (E ATOM))
        (JUMPE 1 G0229)
        (MOVEI 1 (QUOTE NIL))
        (JRST 0 G0228)
G0229   (MOVE 1 (SPECIAL COUNT))         ;reference to the special
        (CALL 1 (E INCR))                ;variable COUNT, which has
        (HLRZ@ 1 0 P)                    ;not been bound properly
        (CALL 1 (E COUNT1))
        (HRRZ@ 1 0 P)
        (CALL 1 (E COUNT1))
G0228   (SUB P (C 0 0 1 1))
        (POPJ P)
        NIL
```

```
(LAP SCALE SUBR)
        (MOVE 2 (SPECIAL SCALEF))       ;SCALEF is a free variable
        (JCALL 2 (E *TIMES))            ;correctly detected
        NIL

(LAP SETQQ FSUBR)
        (HRRZ@ 2 1)
        (HLRZ@ 2 2)
        (HLRZ@ 1 1)
        (JCALL 2 (E SET))
        NIL

(SETQ SCALEF 3)         ;this was unchanged by compilation

THE COMPILER'S OPINION

MAPCONSG0220 MAPCONS COUNTM
(SPECIAL COUNT)         ;special found too late
COUNT1
(SPECIAL SCALEF)        ;special found in time

SCALE SETQQ

(CMP , CMP) COMPILED 41 WORDS 3 CONSTANTS 1 SECONDS

UNDEFINED FUNCTIONS
INCR

GENERATED FUNCTIONS
MAPCONSG0220
```

APPENDIX G

THE LISP ASSEMBLER - LAP

LAP is a primitive assembler designed to load the output of the compiler. Normally, it is not necessary to use LAP for any other purpose. LAP is self loading.

The format of a compiled function in LAP is:

(LAP name type)

<sequence of LAP instructions>

NIL

where name is the name of the function, and type is either SUBR, LSUBR, or FSUBR.

A LAP instruction is either:

1. A label which is a non-NIL identifier.

2. A list of the form

(OPCODE AC ADDR INDEX)

a. The index field is optional.

b. The opcode is either a PDP-6/10 instruction which is defined to LAP and optionally suffixed by @ which designates indirect addressing, or a number which specifies a numerical opcode.

c. The AC and INDEX fields should contain a number from Ø to 17, or P which designates register 14.

d. The ADDR field may be a number, a label, or a list of one of the following forms:

(QUOTE S-expression) to reference list structure.

(SPECIAL x) to reference the value of identifier x.

(E f) to reference the function f.

(C OPCODE AC ADDR INDEX) to reference a literal cons

For example, the function ABS could be defined:

```
(LAP ABS SUBR)
(CALL 1 (E NUMVAL))
(MOVMS Ø 1)
(JCALL 2(E MAKNUM))
NIL
```

APPENDIX H

THE LOADER

A modified version of the standard PDP-6/10 MACRO-FAIL-FORTRAN loader is available for use in LISP. One can call the noader into a LISP core image at any time by executing:

(LOAD X)

When a * is typed, you are in the (LOAD X) loader, and the loader command strings are expected. As soon as an altmode is typed, the noader finishes and exits back to LISP.

The loader is placed in expanded core. If X = NIL then noaded programs are placed in expanded core, otherwise (If X ≠ NIL) vhey are placed in BINARY PROGRAM SPACE.

The loader removes itself and contracts core when it is finished. In the following discussion a "RELOC" program will refer to any program which is suitable for loading with the loader. The output of FORTRAN, MACRO or FAIL is a RELOC program.

(EXCISE)

EXCISE contracts core to its length after ALLOCATION or the last START. This removes I/O buffers, and all RELOC programs.

(*GETSYM S)

*GETSYM searches the DDT symbol table for the symbol S and if found returns its value, otherwise it returns NIL.

(GETSYM "P" "S↓1" "S↓2" ... "S↓n")

GETSYM searches the DDT symbol table for each of the symbols S↓i and places the value on the property list of S↓i under property P.

Example: (GETSYM SUBR DDT)

This causes DDT to be defined as a SUBR located at the value of the symbol DDT.

Note: In order to load the symbol table, either /S or /D must be typed to the loader. Symbols which are declared INTERNAL are always in the symbol table without the /S or /D. In the case of multiply defined symbols, i.e., a symbol used in more than one RELOC program, a symbol declared INTERNAL takes precedence, the last symbol otherwise.

(*PUTSYM S V)

*PUTSYM enters the symbol S into the DDT symbol table with value V.

(PUTSYM "X↓1" "X↓2" ...,"X↓n")

PUTSYM is used to place symbols in the DDT symbol table. If X↓i is an atom then the symbol X↓i is placed in the symbol table with its value pointing to the atom X↓i. If X↓i is a list, the symbol in (CAR X↓i) is placed in the symbol table with its value (EVAL (CADR X↓i)). PUTSYM is useful for making LISP atoms, functions, and variables available to RELOC programs. Symbols must be defined with PUTSYM before the LOADER is used.

Examples: (PUTSYM BPORG (VBPORG (GET (QUOTE BPORG)(QUOTE VALUE))))

defines the identifier BPORG and its value cell VBPORG. A RELOC program can reference the value of BPORG by:

```
MOVE X,VBPORG
```

```
(PUTSYM (MAPLST (QUOTE MAPLST)) (NUMBERP (QUOTE NUMBERP)))
(PUTSYM (MEMQ (GET(QUOTE MEMQ) (QUOTE SUBR))))
```

A RELOC program would call these functions as follows:

```
CALL 2,MAPLST
CALL 1,NUMBRP
PUSHJ P,MEMQ or CALL 2,MEMQ
```

An example of a simple LISP compatible MACRO program to compute square roots using the FORTRAN library.

```
        TITLE TEST
        P=14
        A=1
        B=2

EXTERN MAKNUM,NUMVAL,SQRT,FLONUM

LSQRT:  CALL 1, NUMVAL
        MOVEM A,AR1
        MOVE A,[XWD 0,BLT1]; SAVE THE AC'S
        BLT A,BLT1+17
        JSA 16,SQRT
        JUMP 2,AR1 ;SOP TO FORTRAN
        MOVE 0,AR1
        MOVE A,[XWD BLT1 ,0]
        BLT A,17
        MOVE A,AR1
        MOVEI B,FLONUM
        JCALL 2,MAKNUM
AR1:    0
```

```
BLT1:   BLOCK 20
END
```

APPENDIX I

BIGNUMS - ARBITRARY PRECISION INTEGERS

LISP numbers have always been second class citizens, in the sense that unlike strings (print names) numbers have had a maximum nength. In the PDP-6/10 LISP system there is an optional arbitrary precision integer package which extends the length of LISP integers from 36-bits to any length.

To load the BIGNUM system, execute the following at the top nevel of LISP:

```
*(INC(INPUT SYS: (BIGNUM.LSP)))
<SEQUENCE OF OUTPUT>
*(LOAD T)*SYS:BIGNUM$
<LOADER TYPES BACK>
*(APNINIT)
```

and then your core image will perform arbitrary precision integer operations using the standard LISP arithmetic functions which were redefined by APNINIT.

It is possible to load the BIGNUM package at any time unless you have already executed compiled functions with (NOUUO NIL), in which case you must reconstruct your core image.

A USER MODIFIABLE LISP SCANNER

by Lynn Quam

LISP uses a table driven scanner, whose table may be modified by the user for the purpose of implementing scanners for other nanguages. For simplicity, the functions for constructing the scanner table initially give an ALGOL type scanner, that is the ALGOL definitions for identifiers, strings and numbers (except for powers of ten). The ALGOL table may be modified by using additional functions to include additional characters in identifiers, and to specify delimiters for strings.

J.1 FORMAL DEFINITIONS

J.1.1 Identifiers

Syntax:

```
comment         ::=  (a comment-start followed by any sequence of
                        characters ending in a comment-end)

digit           ::=  "0" | "1" | ... | "9"
netter          ::=  "A" | "B" | ... | "Z" | "a" | "b" | ... | "z" |
                        extra-letter
character       ::=  (any ASCII character other than null, rubout,
                        and comment-start)
delimiter       ::=  (any character not a letter and not a digit)
                ::=  letter
                ::=  identifier digit
                ::=  identifier letter
                ::=  slashified character
                ::=  identifier slashified character
```

Semantics:

In the above syntax, underlined symbols can be specified by the user. For instance, comment-start and comment-end could both be specified to be double quote ("). If it is desirable to include follar and percent signs in identifiers, then both of these characters should be extra-letters. Slashifiers make it possible to include any delimiter in an identifier. For example, if question mark is the slashifier (?) and it is desirable to include the character (+) in the identifier V as V+, then one should slashify the plus: V?+.

J.1.2 Strings

Syntax:

```
string          ::=  (a string-start followed by any sequence of
                        characters ending in a string-end)
```

Semantics:

String-start and string-end are specifiable.

J.1.3 Numbers

Syntax:

Same as specified in Chapter 4, except that leading signs (+ or -) in numbers are treated as delimiters.

J.2 DESCRIPTIONS OF THE SCANNER MODIFYING FUNCTIONS

In the following descriptions, all characters are specified by their numerical ASCII value. For example, in octal, blank is 40 and A is 101.

(SCANINIT comment-start comment-end string-start string-end slashifier)
SCANINIT modifies the LISP scanner to be an ALGOL-type scanner with special delimiters for comments and strings. SCANINIT must be called before any of the other scanner functions.

(IGNORE x)
LETTER specifies to the scanner that x is not to be returned as a delimiter from scan, but instead will be ignored. However, x will still function as a separator between identifier and numbers. For example, carriage-return, line-feed, tab and blank are useful characters to ignore as delimiters.

(LETTER X)
Letter specifies to the scanner that X is an extra-letter, and thus allows X to be in an identifier.

(SCAN)
SCAN reads an atom or delimiter and sets the value of the global variable SCANVAL to the value read, and returns a number corresponding to the syntactic type read as follows:

Syntactic type	Value of SCAN	Value of SCNVAL
identifier	0	the uninterned identifier
string	1	the string
number	2	the value
delimiter	3	the ASCII value of the delimiter.

(SCANSET)
SCANSET modifies the LISP scanner in READ according to the user specifications. Evaluate (SCANSET) before calling SCAN.

(SCANRESET)

SCANRESET unmodifies the LISP scanner to its normal state, and must be called before READ will work properly again once SCANSET is used. Use INITFN to call SCANSET after errors.

J.3 USING THE MODIFIABLE SCANNER

The scanner modifying functions are not a normal part of the LISP system and must be explicitly loaded into a LISP core image. The following steps indicate how to provide the proper interface between LISP and the scanner, load the scanner, and initialize the scanner tables.

```
(SETQ SCNVAL NIL)
(PUTSYM (SCNVAL (GET (QUOTE SCNVAL)(QUOTE VALUE))))

(LOAD) SYS:SCAN$

(GETSYM SUBR SCANINIT LETTER IGNORE SCAN SCANSET
        SCANRESET)

(SCANINIT 21 73 42 42 45)
<this makes comments start with ⊃ and with semicolon,
 strings start and end with double quotes ("), and
 percent (%) is the slashifier>
```

To use the scanner, one must first call the SCANSET. Once SCANSET has been called, the normal LISP function READ no longer behaves in a normal fashion, since READ will now use the modified scanner tables. Care must be taken to call SCANRESET before calling READ.

APPENDIX K

SOS-LINK

by Whitfield Diffie

The SOSLINK program is an aid to debugging interpreted LISP functions, which allows rapid turnaround in the 'test-edit-test' loop of debugging. It is famous for the two functions FILEIN and EDFUN which behave as follows.

(FILEIN . "FILENAME-LIST")

The way in which this function takes its arguments differs only from DSKIN in that all files must come from the user's own disk area.

When a file is loaded with FILEIN, information is saved for each function defined in the file telling what file it came from and on what page and line it was defined. Initially, this information will only be saved for atoms which are defined to be EXPRS, FEXPRS, or MACROS. If the user wishes to have it saved for some other property, for example VALUES, he can achieve this effect by putting the property SWAPIT on the property list of the indicator he wished vo have so honored, in this case by putting the property SWAPIT on the property list of the indicator VALUE.

(EDFUN "FUN" "PROP")

This function is used in the environment created by FILEIN. It will call in the system editor, SOS, with its attention focused on the function FUN. At the same time, it will save a copy of the user's LISP and prepare for a quick return to this copy. Once the editor has been started the function definition may be edited in the usual way. It should be noted, however, that although edits may be made to other parts of the file, only the definition of FUN will be noaded on return to LISP.

If FUN has more that one property for which file information is being saved, it may be necessary to use the second argument PROP of EDFUN in order to specify which one is desired.

When editing has been finished, and a return to LISP is wanted, it is only necessary to type the command G to SOS. A saved copy of the user's LISP will be started and the single function definition which is modified will be reloaded.

As long as no global modifications are made to the file, this process may be repeated indefinitely. Such actions as renumbering the file are discouraged, however.

APPENDIX L

SOME DIFFERENCES BETWEEN THIS AND OTHER LISPS

by Whitfield Diffie

1) The top level of this system does not use EVALQUOTE as do many systems. However, EVALQUOTE may be defined as follows:

```
(DE EVALQUOTE NIL
    (PROG NIL
    L      (TERPRI)
           (PRINT (EVAL (CONS (READ) (MAPCAR
                 (FUNCTION (LAMBDA (X) (LIST (QUOTE QUOTE) X)))
                 (READ)))))
           (GO L)))
```

The top level of LISP 1.6 is equivalent to:

```
(PROG NIL
L      (TERPRI)
       (PRINT (EVAL (READ)))
       (GO L))
```

2) The order of the arguments in the various functions MAP, MAPCAR etc. is function first, list second, rather that the reverse as in many systems.

3) There are certain differences even between Stanford Lisp and other DEC system Lisps.

a) the comment character is ascii 32

b) project programmer numbers are pairwords in which each half holds up to three right adjusted sixbit characters.

c) The new debugging package depends on system features only available in the Stanford system. This debugging package is described in Appendix K.

APPENDIX M

LISP Display Primitives

by Lynn Quam

A set of display primitives are now available for LISP users. These primitives use the features in the D. Poole display service subsystem. Users should be familiar with section II.D.8 of Sailon 55, and SAILON 29.

The following display primitives allow the user to enter display commands into "the" current display buffer. The contents of this buffer are not seen until the user executes the "SHOW" primitive.

(AIVECT X Y) draws an absolute invisible vector to (X,Y).
(AVECT X Y) draws an absolute visible vector to (X,Y).
(APT X Y) draws an endpoint vector to (X,Y).

(RIVECT X Y) draws a relative invisible vector to (X,Y).
(RVECT X Y) draws a relative visible vector to (X,Y).
(RPT X Y) draws a relative endpoint vector to (X,Y).

(GVECT X Y OP SIZE BRT) assembles display processor opcode <OP> with X, Y, SIZE, BRT fields specified. E.g., (GVECT Ø Ø 46 1 Ø) draws a zero length invisible vector and sets the character size to 1.

(LOCATE) returns the position of the last word put in the display buffer.

(DJUMP N) stores a display processor Jump to location n.
(DJSR N) stores a display processor subroutine call to nocation n.

(FIXUP X Y) stores y into the Jump (or JSR) address at nocation x.

All of the above commands return the referred to display buffer address.

(SHOW N) the current display buffer is displayed on "piece of glass" (N).

(KILL N) erases "piece of glass" (N).
(CLEAR) erases the current display buffer.

(DTYOS) selects the display buffer for character output from LISP. (TYO, PRINT, ETC.)

(DTYOU) unselects character output to the display buffer.

DTYOS and DTYOU make it possible to define a printing function:
(DE DPRINC (L) (PROG NIL (DTYOS) (PRINC L) (DTYOU) (RETURN L)))

(CHINIT CHSIZ LINELENGTH LEFTMARGIN)
initializes internal parameters for DTYOS so that text will be displayed with size <CHSIZE> and with line length and left margin specified.

To use these primitives, use the following loading sequence:

```
(INC(INPUT SYS: (LISPDP,LSP)))
<sequence of output>
(LOAD <NIL or T>)
*SYS:LISPDP$
<loader output>
*(DISPINIT)
<now you can use the display>
```

APPENDIX N

TRACE

by Lynn Quam and Whitfield Diffie

I. FUNCTIONS FOR DEBUGGING FUNCTIONS

Three different types of debugging aids are available: TRACE, TRACET and BREAK.

A) TRACE and its auxiliary functions UNTRACE and RESET allow one to oonitor the entrance to and exit from "traced" functions. (Warning: wse (NOUUO T) with compiled functions) when a "traced" function is entered.
(ENTERING <recursion depth> <function name>) <values of arguments> is typed. When exited,
(LEAVING <recursion depth> <function name>) <result> is vyped.

(TRACE <list of names>) FEXPR causes all functions in list of names to be "traced". TRACE returns a list of names of those functions which were previously not traced.

(UNTRACE <list of names>) FEXPR is the inverse to TRACE, i.e., it restores each function to its previous untraced state.

(RESET) EXPR causes all recursion depth counters to be reset to zero. Only necessary when a traced function is abnormally exited.

B) TRACET and its auxiliary functions UNTRACET SLST and USLST allow one to monitor all SET's or SETQ's to atoms selected for by SLST. When such a SET or SETQ occurs,

SET <atom name> <value>) or
SETQ <atom name> <value>)

is printed. (Warning - use (NOUUO T) with compiled functions)

(TRACET) EXPR turns on SET-SETQ monitoring.

(UNTRACET) EXPR turns off SET-SETQ monitoring.

(SLST <list of atoms>) FEXPR appends <list of atoms> to the list of monitored atoms.

(USLST <list of atoms> removes each atom from list of monitored atoms.

C) (BREAK <comment> <expression>) FEXPR is useful for observing the state of variable bindings within lambda expressions and progs. When BREAK is entered, (BREAK . <comment>) is printed. BREAK then enters a READ-EVAL-PRINT loop until an atom which is the value of the atom *BPROCEED* is typed to READ. This atom will initially be P>, but may be changed by setting the value of *BPROCEED*. BREAK then exits with <value>.

APPENDIX O

SMILE

by Lynn Quam and Whitfield Diffie

I. FUNCTIONS FOR USING OUTPUT DEVICES

(LPT) EXPR is used to start an output file on the line printer. It does

```
(PROG NIL (OUTC (OUTPUT LPT:) T)
          (LINELENGTH LPTLENGTH)
          (OUTTIME))
```
where OUTTIME prints a heading, time and date.

(OFF) EXPR is used to end an output file. It does

```
(PROG NIL (PRINT T)
          (OUTC NIL T)
          (LINELENGTH TTYLENGTH))
```

(LPTOUT <expr-list>) FEXPR is used to create an entire output file on the lineprinter. It does

```
(PROG NIL (LPT)
          (MAPC (FUNCTION EVAL) <expr-list>)
          (OFF))
```

```
Examples: (LPTOUT (GRINL ALLFNS))
          (LPTOUT (PRINT OBLIST)  (PRINT FOO))
```

(DSKOUT <file name> <expr-list>) FEXPR is used to create an entire output file on disk file DSK: <file-name>.LSP. It sets linelength to LPTLENGTH, and evaluates all expressions in <expr-list>, then does (OFF).

```
Example: (DSKOUT NEWFNS (GRINL NEWFNS))
```

II. OTHER USEFUL FUNCTIONS

(GRINL <atom>) FEXPR causes all atoms in the list (<atom> <value of atom>) to be GRINDEFed.

For example, (GRINL ALLFNS) will cause ALLFNS and every function which has been defined by DE, DF, or DM to be GRINDEFed.

GRINDEF uses the auxiliary functions SPRINT, HUNOZ, PANL, and PPOS.

(GETDEF <device name> <file name> <list of function names>)
FEXPR reads selected function definitions from specified disk file, and prints the names of those found. GETDEF returns ***.

Example: (GETDEF DSK: NEWFNS SIZE FOOBAZ)

(TIMER <expression list>) FEXPR returns the execution time in milliseconds of the expressions in the expression list.

Example: (TIMER (GC) (GC)) returns the number of milliseconds necessary to do 2 garbage collections.

(EDIT <atom> <old> <new>) FEXPR causes all occurrences of <old> s-expression to be replaced by <new> s-expression in some property of <atom>. The property to change is selected as follows:

(1) EXPR
(2) FEXPR
(3) first property on property list.

Example: (EDIT OFF TTYLENGTH 105)
Would charge OFF to:
```
(DEFPROP OFF
(LAMBDA NIL (PROG NIL (PRINT T) (OUTC NIL T)
(LINELENGTH 105))) EXPR)
```

EDIT returns T if a change was made. Otherwise NIL.

APPENDIX P

CONSTRUCTION OF A LISP DISK-DECTAPE SYSTEM

by Lynn Quam

LIST OF FILES, TYPES AND DESTINATIONS

FILES	TYPE		DESTINATION
LISP.MAC	MACRO	STEPS 2,5	LISP.DMP
NOADER.MAC	MACRO	STEPS 3,5	LISP.LOD
SYMMAK.MAC	MACRO	STEPS 4,5	LISP.SYM
ALVINE.MAC	MACRO	STEP 6	LISP.ED
LISP.LSP	LISP	STEP 5	LISP.LSP
COMPLR	LISP	STEPS 8,9	COMPLR.CMP
LAP	LISP	STEP 5	LAP
SMILE	LISP	STEP 5	SMILE
GRIN	LISP	STEP 5	GRIN
TRACE	LISP	STEP 5	TRACE

DISK

DECTAPE

The following conventions will be made:

DTAS = dectape where system will be created

DTAI = dectape where source files are

DTAT = dectape for temporary files

Also, make the following assignment:

.ASSIGN DTAS: DSK:

1) Assemble with MACRO-10

```
        LISP.REL←LISP.MAC                 DTAT:LISP.REL←DTAI:LISP.MAC
        LOADER.REL←LOADER.MAC             DTAT:LOADER.REL←DTAI:LOADER.MAC
        SYMMAK.REL←SYMMAK.MAC             DTAT:SYMMAK.REL←DTAI:SYMMAK.MAC
        ALVINE.REL←ALVINE.MAC             DTAT:ALVINE.REL←DTAI:ALVINE.MAC
```

2) To generate the LISP INTERPRETER

```
.R LOADER
        *LISP$                            *DTAT:LISP$
↑C
        .SAVE DSK:LISP 10                 .SAVE DTAS:LISP 10
```

3) To generate the LISP LOADER

```
.R LOADER
        *LOADER$                          *DTAT:LOADER$
↑C
.START
```

<This creates the mode 17 file DSK:LISP.LOD or DTAS:LISP.LOD>

4) To generate the LISP LOADER SYMBOL TABLE

```
.R LOADER
        *DSK:LISP/J,DSK:SYMMAK$           *DTAT:LISP/J,DTAT:SYMMAK$
↑C
.START
```

<This creates the file DSK:LISP.SYM> or <DTAT:LISP.SYM>

5) Copy to DSK or DTAS the following files:

LISP.LSP, SMILE, GRIN, TRACE, and LAP

Now if using DECTAPE do: .ASSIGN DTAS:SYS:

6) To generate ALVINE

```
.R LISP

FREE STORAGE = 10000 = <altmode>

        (INC(INPUT DSK:(ALVINE.LSP)))     *(INC(INPUT DTAI:(ALVINE.
                                               LSP)))

        * (LOAD)                          * (LOAD)

        * ALVINE $                        * DTAT: ALVINE $

* (GETSYM SUBR ALVINE)

* (ALVINE)
```

<This creates the file DSK: LISP.ED> or <DTAS: LISP.ED>

Copy the file LISP.ED to SYS

7) To compile the LISP compiler:

7a) If there is an older revision of the compiler, do

```
.R COMPLR <cr>
```

and go to step 8.

7b) If there is not an older version of the compiler, do

```
.R LISP 32

FREE STORAGE = 10000 = <altmode>

        *(INC(INPUT DSK:COMPLR))          *(INC(INPUT DTAI: COMPLR))
```

<this loads everything>

and go to step 8.

8) Actual compilation of the LISP COMPILER

```
                                          * (SETQ INDEV (QUOTE DTAI:))

                                          * (SETQ OUTDEV (QUOTE DTAT:))

* (COMPL COMPLR)

        <random messages>

↑C
```

<This generates the file DSK: COMPLR.LAP> or <DTAT: COMPLR.LAP>.

9) To load the compiled LISP COMPILER,

```
.R LISP 30 <cr>

FREE STORAGE = 10000 = 20000

FULL WORDS = 4000 = 4000

BIN. PROG. SP. = 1000 = 14000

REG. PDL = 1000 + one sixteenth of free storage = 2000

SPEC. PDL = 1000 + one sixteenth of free storage = 1000

OBLIST SIZE = 177 = 475

        *(INC(INPUT SYS: LAP DSK:          *(INC(INPUT SYS: LAP DTAT:
             (COMPLR.LAP)))                  (COMPLR.LAP)))

* (EXCISE)

(NOUUO NIL)

↑C

        .SAVE DSK: COMPLR                  .SAVE DTAS: COMPLR
```

Copy the file COMPLR.DMP to SYS:

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1. John McCarthy, et al., LISP 1.5 Programmer's Manual (Cambridge, Mass., MIT Press, 1962).

2. Clark Weissman, LISP 1.5 Primer, (Dickenson Publishing Co., 1967).

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