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LISP

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LISP is a source language for writing algorithms. Unlike most other languages, in which a source program consists of a sequence of instructions to be executed in a certain order, a LISP program usually (but not always) consists of a collection of function definitions.

The basic object in LISP is a branching-tree type of structure called an S-expression. All function definitions, function arguments, function values, programs, instructions, variables, constants, and data are S-expressions. At each node of an S-expression there are two branches. The branches eventually terminate in atoms. An S-expression is thus defined recursively - it is either an atom or the concatenation of two S-expressions.

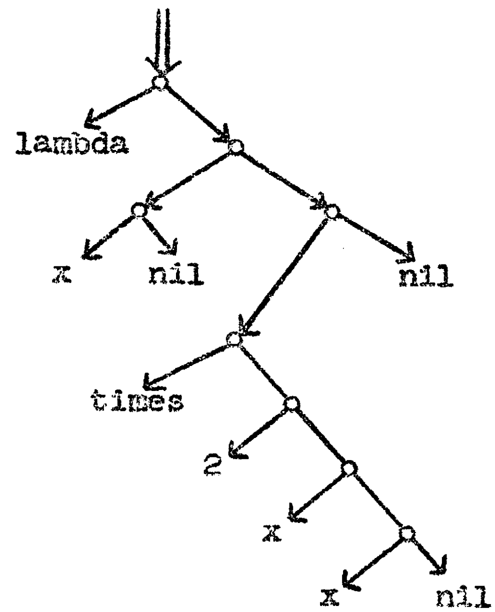


fig. 1 - an S-expression

In the S-expression of figure 1, lambda, x, nil, times, and 2 are atoms. The S-expression is the concatenation of the S-expression lambda, which is an atom, with another concatenation.

There is a notation for transmission of S-expressions between LISP and the outside world. An atom is simply spelled out. A concatenation is written as a left parenthesis, the S-expression on the left side, a period, the S-expression on the right side, and a right parenthesis. The S-expression of figure 1 could be written

(lambda.((x.nil).((times.(2.(x.(x.nil)))).nil)))

Almost all S-expressions that are commonly used have a chain of branches going off to the right, with the atom nil at the end. From each node an S-expression hangs on the left. Such an S-expression is called a list.

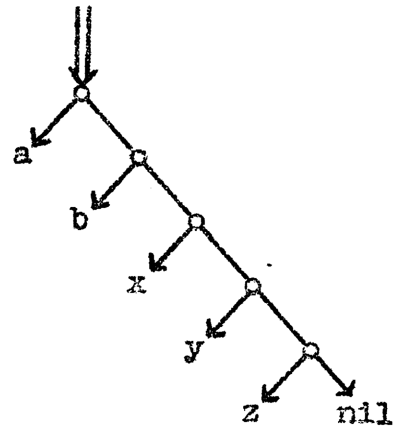


fig. 2 - a list

There is a special notation for lists, consisting of a left parenthesis, the items of the list with spaces separating them, and a right parenthesis. Using list notation, the S-expression of figure 2 is written

(a b x y z)

and that of figure 1 is written

(lambda (x) (times 2 x x))

Either format is permissible for input. In typing out S-expressions, LISP uses list notation wherever possible.

There are two types of atoms. Numbers consist of one or more digits, with or without a minus sign. Atomic symbols contain at least one non-numeric character.

The three most basic functions in LISP are <u>car</u>, <u>cdr</u>, and <u>cons</u>. These three, along with over 50 others, exist as subroutines in the LISP program.

Given a nonatomic S-expression as an argument <u>car</u> finds the left half. <u>Cdr</u> finds the right half.

car of (a.b) = a
cdr of (a.b) = b

<u>Cons</u> takes two arguments and concatenates them.

cons of a and b = (a.b)

Note that the <u>car</u> of a list is its first element, and the <u>cdr</u> is the list of the remaining elements. The list of no elements is the atomic symbol <u>nil</u>.

car of (a b c) = a
cdr of (a b c) = (b c)
cdr of (a) = nil

The *cons* of an S-expression and a list is the list with the S-expression tacked onto the front.

cons of a and (b c) = (a b c)

LISP does arithmetic with the functions *plus*, *minus*, *times*, *logor*, *logand*, *logxor*, *quotient*, and *remainder*. The arguments of these functions must be numbers. *Plus*, *times*, *logor*, *logand*, and *logxor* take any number of arguments and calculate the sum, product, bitwise inclusive or, bitwise and, and bitwise exclusive or of all of the arguments. *Minus* takes one argument and returns its negative (ones complement). *Quotient* and *remainder* take two arguments and return the quotient and remainder of the integer division of the first by the second.

LISP uses the atomic symbols *t* and *nil* to represent truth and falsehood, respectively. Decisions are made by functions called predicates. A predicate applies a test to its argument and returns *t* or *nil* depending on the result.

Atom returns *t* if its argument is an atom (number or atomic symbol) and *nil* if it a concatenation.

Numberp returns *t* only if its argument is a number. It returns *nil* if it is an atomic symbol or a concatenation.

Null returns *t* if its argument is *nil*, and returns *nil* otherwise.

Equal takes two arguments and returns *t* if they have the same structure, i.e. if they would look alike if printed out.

The argument of *zerop* must be a number. It returns *t* if that number is plus zero.

Greaterp takes two numeric arguments and returns *t* if the first is algebraically strictly greater than the second.

Predicates are usually used with *cond*, the decision making function. *Cond* takes an indefinite number of arguments, each of which is a list of two items - an antecedent and a consequent. The arguments are examined one at a time until an antecedent is found to be true. The value of the corresponding consequent is then returned. If all of the antecedents are false an error message is printed. The antecedent of the last argument is usually *t* to prevent this.

Logical quantities are manipulated with the funcions *and* and *or*. Each takes an indefinite number of logical arguments and returns *t* if all of them or one of them, respectively, is true. There is no function named *not*, but *null* may be used to negate logical quantities. Remember that *logand* and *logor* are used with numerical quantities, *and* and *or* with logical ones.

Atomic symbols have the property that they may "stand for" things. The thing for which an atomic symbol stands is called its value. It may be any S-expression, atomic or otherwise. The value of an atom may be the atom itself, as is the case with t and nil. When an atom has a value, it is said to be bound to that value. Not all atoms are bound. The predicate valp may be used to determine whether an atomic symbol has a value.

The function setq is used to bind atomic symbols. The first argument is the symbol, the second is the value. Any previous value of the symbol is lost. Setq is an example of a pseudo-function. It is used for its effect rather than its value. Pseudo-functions, like all other functions, must return values, but the value is usually ignored. Setq returns its second argument.

In LISP function calls are written as S-expressions, using a variation of Polish notation. The S-expression used is a list containing the function as the first item and the arguments as the remaining items. Every function must therefore be able to be written as an S-expression. For this purpose, associated with each internal function in LISP is an atomic symbol with the same name. The value of the symbol is a number with an invisible flag giving the LISP program the information it needs to call the subroutine.

Suppose, for example, that x stands for a and y stands for (b c), and one wishes to take the cons of x and y, obtaining (a b c). The atomic symbol cons is used, and the call is the S-expression (cons x y). Note that the car of a function call is the function, and the cdr is the argument list. The procedure by which the S-expression (cons x y) is transformed into (a b c) is called evaluation, and is the most important procedure in LISP. Evaluation of a number gets the number itself. Evaluation of an atomic symbol gets the symbol's value. Evaluation of a nonatomic S-expression (which must be a list) causes the arguments (in most cases) to be evaluated, and their values sent to the function. Whether the arguments of a function are evaluated or not is a property of the function. Except where otherwise specified, all functions have their arguments evaluated.

Since the arguments of functions are evaluated, they may be other function calls, enabling functions to be nested within each other. For example, to take the car of the cdr of the car of whatever x is bound to, evaluate

```
(car (cdr (car x)))
```

If x evaluates to (1.3), then

```
(plus (minus (car x)) 5 (cdr x))
```

evaluates to 7.

Evaluation may be stopped with the function quote. Quote takes one argument and returns it without evaluation. To find the cons of a and (b c), obtaining (a b c), evaluate (cons (quote a) (quote (b c)))

LISP will evaluate (quote a) to a and (quote (b c)) to (b c) before sending them to cons. Evaluating (cons a (b c)) would cause the value of c to be sent to the function b, and the value of a concatenated with the result.

The function setq evaluates its second argument but not its first. To bind x to (a b c), evaluate

(setq x (quote (a b c)))

x may be set to 1 more than its previous numerical value by evaluating

(setq x (plus x 1))

The funcion cond does not evaluate its arguments directly but evaluates the antecedents and consequents separately. The antecedent of each argument is evaluated until one is found to have a value of t. The consequent is then evaluated.

```
(cond ((atom x) (quote a)) (y (quote (a b)))
      (t (quote (a b c))))
```

```
evaluates to  a        if the value of x is atomic, or
              (a b)    if the value of y is t, or
              (a b c)  otherwise.
```

The third case works because t and nil are bound to themselves.

In addition to functions written as subroutines, functions may be written by the programmer. These functions are interpreted by LISP when they are called. A programmed function is a list of three items, the first of which is usually the atomic symbol lambda. Lambda is not a subroutine but a special symbol which LISP recognizes. It has no value. Like subroutines, programmed functions are usually given names, and an atomic symbol of the same name is given a value of the function. Functions defined with lambda are called expr's and always have their arguments evaluated.

Suppose the symbol foo has a value of

(lambda (x) (times 2 x x))

Lambda identifies it as an expr, (x) is the dummy symbol list, indicating that it takes one argument, and (times 2 x x) is the actual definition. This function takes one argument, squares it, multiplies by 2, and returns the result.

```
(foo (plus 1 2)) evaluates to 18
(foo (foo 1)) evaluates to 8
```

A predicate symbp to detect whether an S-expression is an atomic symbol could be written as

```
(lambda (x) (and (atom x) (null (numberp x)))), or as

(lambda (y) (cond
   ((numberp y) nil)
   ((atom y) t)
   (t nil)
))
```

This predicate, if defined, could be used exactly as one would use atom or numberp. Programmed functions may call any functions, even themselves.

A function fact to find the factorial of a number could be written as

```
(lambda (x) (cond ((equal x 1) 1)
   (t (times x (fact (plus x -1))))))
```

(fact 4) evaluates to 24
(fact (fact 3)) evaluates to 720

When LISP attempts to evaluate a function call, that is, a nonatomic S-expression, it evaluates the function as many times as necessary (usually once) until a subroutine or a list beginning with lambda, nlamda, or label is found. If lambda is found, the arguments are evaluated and paired with the symbols on the dummy symbol list. Any old values of these symbols are saved, and the symbols are bound to the evaluated arguments. The definition is then evaluated and, after restoring the previous bindings of the dummy symbols, the value of the definition is returned as the value of the call. Example - suppose that the second definition of symbp is used. Find out whether a is a symbol.

symbp evaluates to (lambda (y) (cond ((numberp y) nil)
   ((atom y) t) (t nil)))
y evaluates to (1 2 3). This is its previous value
   from some unrelated calculation.
Evaluate (symbp (quote a)).

The function symbp is evaluated to
(lambda (y) (cond (numberp y) nil) ((atom y) t) (t nil)))
LISP recognizes this as an expr, so it evaluates each
   argument
   (quote a) is evaluated - its value is a
The dummy symbol list is (y). The old value of y, (1 2 3),
   is saved.
y is bound to the evaluated argument.
y now evaluates to a.
(cond ((numberp y) nil) ((atom y) t) (t nil)), the
   definition of the function, is evaluated. Cond, unlike most
   functions, does not evaluate its arguments immediately, so
   the arguments sent to cond are
   ((numberp y) nil), ((atom y) t), and (t nil).
(numberp y), the first antecedent, is evaluated.
Numberp evaluates its argument.

y is evaluated, obtaining a, which is sent to numberp.
a is not a number, so numberp returns nil.
cond goes to the next antecedent.
(atom y) is evaluated.
y evaluates to a, which is an atom, so atom returns t.
The second statement is true, so its consequent, t, is evaluated.
t is bound to itself, so the value of the call to cond is t.
y is restored to (1 2 3), its old value, and t is returned as the value of (symbp (quote a)).
Hence a is a symbol.

Functions like symbp and fact, being values of atomic symbols, are relatively permanent and may be used repeatedly. When one wishes to use a function only once, it is not necessary to give it a name and bind the atomic symbol of the same name to it. The function itself may be used. Hence

```
((lambda (y) (cond ((numberp y) nil) ((atom y) t)
   (t nil))) (quote a))
```

may be used to determine that a is a symbol.

If a function is recursive, however, it must be given a name so that it may use that name in calling itself. An attempt to calculate 4 factorial by evaluating

```
((lambda (x) (cond ((equal x 1) 1) (t (times x (fact
   (plus x -1)))))) 4)
```

would not work because fact has no value.

```
((label fact (lambda (x) (cond ((equal x 1) 1) (t (times
x (fact (plus x -1)))))))) 4)
```

will work. Label is used to temporarily bind the atomic symbol fact to the definition of the factorial function.

A list consisting of label, a symbol, and a function is equivalent to the function alone, except that the symbol is temporarily bound to the function. The function can therefore call itself by referring to the symbol with which it is labelled. The previous value of the symbol is restored when the function is finished.

To write a function which does not have its arguments evaluated, use nlamda instead of lambda. Functions defined in this way are called fexpr's. In addition to not evaluating their arguments, they also have a different way of binding arguments to the dummy symbol list. A fexpr may take any number of arguments. There must be exactly one symbol on the dummy symbol list. It will be bound to the list of all of the arguments. Functions which do not evaluate their arguments are usually used only on the top level for "utility" purposes. Other functions do not, as a rule, call them, and they are not usually recursive. Prindef, dex, fix, trace, and untrace are examples of internal functions which do not evaluate their arguments.

Expr's may be conveniently defined by means of the pseudo-function dex. Dex takes three arguments and does not evaluate them. The first is the name of the function to be defined, the second is the dummy symbol list, and the third is the definition.

```
(dex symbp (y) (cond ((numberp y) nil)
    ((atom y) t) (t nil)))
```

evaluates to symbp and defines symbp to be the expr described above.

Programs in the usual sense may be written with the functions prog, return, and go. Prog takes an indefinite number of arguments and does not immediately evaluate them. The first argument is the temporary variables list. The value of each symbol on this list is saved, and each symbol is bound to nil. These symbols may be used for temporary storage by the program, and will have their original values restored upon exit. Of the remaining arguments, atomic symbols are interpreted as address tags and nonatomic expressions as instructions. The previous values of the tags are saved, and the tags are bound to pointers to the appropriate points in the program. The instructions are then evaluated in sequence, and the values ignored. If the program runs out of instructions, nil is returned. If the function return is called, its evaluated argument is returned as the value of the program. In either case the temporary variables and address tags are restored. The function go, with an address tag as an argument, causes a transfer of control to the point indicated. Prog, like other functions, may be nested. Return and go always refer to the most recently entered prog. Program variables of nested progs are saved independently at each level. On the top level of a prog the rules for use of cond are relaxed. If cond runs out of propositions, rather than giving an error message it simply goes to the next statement of the program.

A typical use of prog is in the function reverse, which reverses a list. Reverse could be defined by

```
(dex reverse (x) (prog (y)
z  (cond ((null x) (return y)))
   (setq y (cons (car x) y))
   (setq x (cdr x))
   (go z)
))
```

This takes advantage of the facts that the program variable is initially bound to nil and that a cond may run out of propositions in a prog.

LISP keeps a symbol table similar to those used by debuggers and assemblers, containing an entry for each symbol, whether it has a value or not. This table initially contains one entry for each subroutine, with a name the same as that of the subroutine and a value of a number with the invisible flag subr or fsubr.

t and nil, with values of themselves

lambda, nlamda, label, subr, and fsubr, with no values. These are flags used internally by the LISP program.

Whenever an atomic symbol not appearing in the table is read in, it is placed in the table with no value. It may later be given a value.

The value of an atomic symbol is stored on the car of that symbol. Taking the car of an atomic symbol gets its value. It is illegal to take the car of a symbol with no value, and it is very dangerous to take the car of a number. The cdr of a symbol is normally nil, but any S-expression may be stored there by the programmer.

S-expressions which look alike may occupy different locations of memory. Expressions may also be different but share common sub-expressions. Whenever an S-expression is read in, a fresh copy of it is created in memory, even if another copy already exists. Only atomic symbols are in unique locations. For example, reading and evaluating

```
(setq x (quote ((a.b) (c.d)))) and
  (setq y (quote ((a.b) (c.d))))
```

leaves memory looking like this -

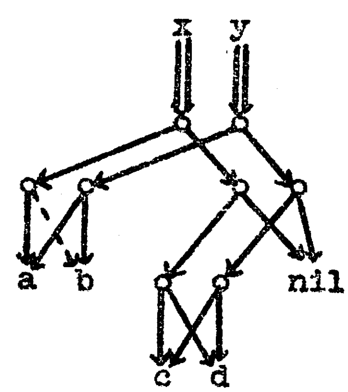


fig. 3 - non-identical S-expressions

x and y will both print out as ((a.b) (c.d)), and will satisfy the predicate equal, but they will not be identical. Another predicate, eq, may be used to test for exact identity between two S-expressions. In the example above, (eq x y) would evaluate to nil. If x and y had been bound by

```
(setq x (quote ((a.b) (c.d)))) and
          (setq y x)
```

they would be identical and would satisfy eq.

Equal could have been written in terms of *eq* as

```
(dex equal (x y) (cond
  ((and (numberp x) (numberp y)) (zerop (logxor x y)))
  ((or (numberp x) (numberp y)) nil)
  ((and (atom x) (atom y)) (eq x y))
  ((or (atom x) (atom y)) nil)
  (t (and (equal (car x) (car y)) (equal (cdr x) (cdr y))))
))
```

There are two S-expression modifying functions, *rplaca* and *rplacd*, each taking two arguments and evaluating both. They replace the *car* and *cdr*, respectively, of the first argument with the second argument, and return the modified first argument. If *x* and *y* are bound as in figure 3, *(rplacd (car x) (quote q))* removes the dotted line in the figure and replaces it with a pointer to the atomic symbol *q*. It returns *(a.q)*, its modified first argument. The value of *x* is now *((a.q) (c.d))*. The value of *y* is not changed. If *y* had been bound by *(setq y x)*, so that its value was identical with that of *x*, it too would have been changed. Since the *car* of an atomic symbol is its value, *rplaca* may be used to bind symbols, and *rplacd* may be used to store S-expressions on the *cdr* of a symbol.

Other S-expression manipulating functions

Caar, *cadr*, *cdar*, and *cddr* are compositions of *car* and *cdr*. They could have been defined by

```
(dex caar (x) (car (car x)))
(dex cadr (x) (car (cdr x)))
(dex cdar (x) (cdr (car x)))
(dex cddr (x) (cdr (cdr x)))
```

For example, the *cadr* of *(a b c)* is the *car* of the *cdr* of *(a b c)*, or *b*.

List takes (and evaluates) an indefinite number of arguments and returns the list of them. *List* and *cons* are the two functions that are used to create complex S-expressions out of small ones.

```
(list 1 (cons (quote a) (quote b)) (plus 1 2 3))
   evaluates to (1 (a.b) 6)
```

Append takes two arguments, which must be lists, and appends them.

```
(append (quote (a b c)) (quote (d e f)))
   evaluates to (a b c d e f)
```

Append makes a copy of the first list in order to avoid modifying it. *Append* could have been defined by

```
(dex append (x y) (cond
   ((null x) y)
   (t (cons (car x) (append (cdr x) y)))
```

))

Nconc is the same as append except that it does not copy its first argument but merely changes the nil at the end of the first list to the second list. In doing so the first list is permanently modified. Nconc could have been defined by

```
(dex nconc (x y) (cond
   ((null x) y)
   (t (prog (z)
        (setq z x)
a       (cond ((null (null (cdr z))) (go b))
        (rplacd z y)
        (return x)
b       (setq z (cdr z))
        (go a)
))))
```

Reverse takes one argument, which is a list, and reverses it. It could have been defined by

```
(dex reverse (x) (prog (y)
a    (cond ((null x) (return y)))
     (setq y (cons (car x) y))
     (setq x (cdr x))
     (go a)
))
```

Subst takes three arguments and substitutes the first for all appearances, on all levels, of the second in the third. The third argument is not actually modified. Subst could have been defined by

```
(dex subst (x y z) (cond
   ((equal y z) x)
   ((atom z) z)
   (t (cons (subst x y (car z)) (subst x y (cdr z))))
))
```

Sassoc takes three arguments and looks up the first in the second, which is a special type of table called an association list. An association list is a list of dotted pairs of atomic symbols with the S-expressions associated with them. For example, to keep a table with the information

x=1 y=2 z=3

and not bind x, y, and z to these values, one could bind tab to

((x.1) (y.2) (z.3))

Sassoc can look through a table in this format. It returns the first pair which has a car identically equal to the first argument.

(sassoc (quote y) tab no) evaluates to (y.2)

The third argument is a function of no variables which is called if the item is not found.

```
(sassoc (quote z) tab (quote (lambda nil
    (quote (not found)))))
```

evaluates to (z.3). If z had not been found, (not found) would have been returned as the value of the call to sassoc. In order to save space in memory, a number may be used as the third argument. If the search fails the uaf error message will be printed along with the number. Sassoc could have been written as

```
(dex sassoc (x y z) (cond
    ((null y) (z))
   ((eq x (caar y)) (car y))
    (t (sassoc x (cdr y) z))
))
```

Other predicates

Member takes two arguments, the second of which is a list, and returns t if the first argument is a member of that list. Equal is used for the comparison, so any S-expression may be tested. The second argument is searched on the top level only. Member could have been defined by

```
(dex member (x y) (cond
    ((null y) nil)
    ((equal x (car y)) t)
    (t (member x (cdr y)))
))
```

I/O operations

Read takes no arguments. It reads one S-expression from the typewriter or tape reader and returns that S-expression.

(read) evaluates to (a b c d) if the latter is typed in.

Prin1 takes one argument, which must be an atom. It prints and/or punches it with no extra punctuation. The value returned is the original argument.

Print takes one argument, which may be any S-expression. It prints and/or punches it preceded by a carriage return and followed by a space. The argument is returned.

(print (quote (a b c))) prints out "↵
(a b c)␣" and returns (a b c)

Terpri prints and/or punches a carriage return. It takes no arguments and returns nil.

Stop takes no arguments. It waits for a character to be typed on the typewriter and then returns nil. A call to stop is normally punched at the end of each tape in order to give the operator time to load a new tape or change sense switches.

Miscellaneous functions

Gensym takes no arguments. Each call to gensym creates a new atomic symbol as if it had been read in and returns that symbol. The names of the symbols are g00001, g00002, etc.

Eval takes one argument and returns its value. This means that the argument is actually evaluated twice. If x is bound to (cons 1 3), the value of (eval x) is (1.3), whereas the value of x alone is (cons 1 3).

Apply takes two arguments, a function and an argument list for the function. The function is called with the given arguments. If the function is one which normally evaluates all its arguments, they will not be evaluated again, but simply taken from the second argument to apply, which was, of course, evaluated already.

(apply (quote cons) (quote (a b))) sends a and b, without further evaluation, to cons, thereby returning (a.b).

Trace takes any number of arguments and does not evaluate them. Each argument should be the name of an expr (function using lambda). Each function is traced, or modified so that it prints out its name and evaluated arguments on entry, and its name and returned value on exit. Nested or recursive functions cause the printouts to occur in proper order at each entry and exit.

If fact initially had a value of

```
(lambda (x) (cond ((equal x 1) 1) (t (times
   x (fact (plus x -1))))))
```

(trace fact) would evaluate to t and redefine fact as

```
(lambda (x) (prog (99g)
   (print (quote (enter fact)))
   (print (list x))
   (setq 99g
      (cond ((equal x 1) 1) (t (times
         x (fact (plus x -1))))))
   (print (quote (value fact)))
   (return (print 99g))
))
```

Evaluation of (fact 3) would return 6 after printing

```
(enter fact)
(3)
(enter fact)
(2)
(enter fact)
(1)
```

```
(value fact)
1
(value fact)
2
(value fact)
6
```

Untrace takes any number of arguments and does not evaluate them. Each argument should be the name of a traced function. _Untrace_ restores each function to its original definition.

Prindef is used to punch out the definitions of functions and constants. It takes any number of arguments and does not evaluate them. Each argument should be an atomic symbol with a value. _Prindef_ punches the definition of each symbol as a call to _rplaca_, and then returns a call to _stop_, which is normally punched also. The resultant tape, when read in at a later time, defines the atoms and then waits for a character from the typewriter.

(prindef fact) punches

```
(rplaca (quote fact) (quote (lambda (x) (cond ((equal x 1) 1)
(t (times x (fact (plus x -1))))))))

(stop)
```

Prindef could have been defined by

```
(setq prindef (quote (nlamda (x) (prog nil
a   (cond ((null x) (return (quote (stop)))))
    (print (list
       (quote rplaca)
       (list (quote quote) (car x))
       (list (quote quote) (eval (car x)))
    ))
    (terpri)
    (setq x (cdr x))
    (go a)
))))
```

Fix is used to edit or modify functions. It takes three arguments and does not evaluate them. The third is the name of the function to be fixed. The first argument is substituted for the second in each appearance in the function, and the function is redefined to be the result. _Fix_ could have been defined by

```
(setq fix (quote (nlamda (x)
    (rplaca (car (cddr x)) (subst (car x) (cadr x)
      (eval (car (cddr x)))))
)))
```

Prog2 is used to cause the evaluation of two functions with a single call to _eval_. It takes two arguments, evaluates both, and returns the second. _Prog2_ could have been defined by

```
(dex prog2 (x y) y)
```

Nconc could have been written more efficiently using prog2 -

```
(dex nconc (x y) (cond
   ((null x) y)
   (t (prog (z)
       (setq z x)
a      (cond ((null (cdr z)) (prog2 (rplacd z y) (return x))))
       (setq z (cdr z))
       (go a)
))))
```

Maplist is used to send each item of a list to a function as the single argument of that function, and return the list of the values returned. Maplist takes two arguments and evaluates both. The first is the list of arguments, the second is the function. To cons each item of the list (a b c d) with x, for example, evaluate

```
(maplist (quote (a b c d))
   (quote (lambda (y) (cons y (quote x)))))
```

obtaining

```
((a.x) (b.x) (c.x) (d.x))
```

Maplist could have been defined by

```
(dex maplist (x y) (cond
   ((null x) nil)
   (t (cons (apply y (list (car x))) (maplist (cdr x) y)))
))
```

Output

Output normally goes to the online typewriter. If sense switch 3 is up output goes to the punch also. Sense switch 6 independently suppresses type-out. The punch is automatically assigned and dismissed as needed. Error messages are always printed on the typewriter only.

S-expressions which are nearly lists, such as

(a.(b.(c.d)))

are printed as

(a b c.d)

This format is also acceptable for input.

Numbers are printed as signed integers, in octal if sense switch 4 is up, in decimal otherwise. Sense switch 4 is interrogated only after reading or printing a number.

A carriage return is printed after every 63 characters of output not containing a carriage return.

Input

Input comes from the tape reader if sense switch 5 is down and from the typewriter if up. The reader is automatically assigned and dismissed as needed. A call to subroutine stop always clears the time-sharing reader buffer. After turning off sense switch 5 it is necessary to type a carriage return to start reading tape.

Carriage return and stop code are ignored.

Parentheses, period, and space separate atoms. Extra spaces may be used anywhere except inside an atom. Spaces may be omitted except where needed to separate atoms. Tab and comma are equivalent to space. () is equivalent to nil. When an S-expression consists of an atom only it must be followed by a separation character, usually space. This separator is saved and used on the next call to read.

0 to 7 in octal radix (sense switch 4 up) and 0 to 9 in decimal radix are digits. An atom containing only digits, with an optional minus sign, is a number. Plus signs are not permitted in numbers. The absolute value of a number must not exceed 131071 decimal or 377777 octal.

Other characters, including case shifts and all upper-case characters, are letters, and atoms containing one or more letters are atomic symbols. All atoms must begin and end in lower case. Atomic symbols are limited to six characters plus a lower case shift at the end if needed. Atomic symbols longer than this are truncated.

Backspace may be used to correct errors in typing. After one or more characters of an atom have been typed, backspace deletes those characters and starts the atom over. The remainder of the S-expression is not affected. A backspace immediately after a separation character starts the entire S-expression over and prints out a carriage return.

Operation

Read in the tape, set the sense switches as desired, and start at zero. LISP reads S-expressions and prints out their values. The LISP program could be simulated by

```
(prog nil a (print (eval (read))) (go a))
```

Some other LISP programs, notably the version used on the 7094, use a different algorithm, in which a function and its argument list are typed in as two separate S-expressions, and the arguments are not evaluated on the top level. This algorithm may be approximately simulated by

```
(prog nil a (print (apply (read) (read))) (go a))
```

When first starting LISP, if sense switch 2 is on, core 1 is assigned and used. About three times as much free storage is available when using 8K as when using 4K.

If sense switch 1 is on when LISP is started, functions may be deleted, resulting in more available free storage and symbol table space. Subroutines may be deleted only in a specified order, and deletion of any subroutine requires deletion of all that precede it. After LISP prints out each subroutine name, it listens for a character from the typewriter. If "x" is typed, the subroutine is deleted and LISP prints the next one. If any other character is typed, the subroutine is not deleted, and LISP begins normal operation. The order in which subroutines may be deleted is

trace (deletes untrace also), reverse, fix, subst, dex, prindef, sassoc, gensym, member, nconc, append, maplist, or, and, quotient, remainder, greaterp, logxor, logor, logand, times, plus, minus, equal, and eq.

LISP may be stopped at any time except during a garbage collection by hitting call and starting at location zero. Temporary bindings that are in effect at that time will not be removed, but this rarely causes difficulty. Starting at zero during a garbage collection will usually destroy most of free storage. LISP indicates that it is garbage collecting by turning on the coordinate lights on the cathode ray display.

LISP may execute an illegal instruction if an improper operation is performed, such as an attempt to bind a number. Starting at zero is usually safe in this case.

Upon detection of an error, LISP prints a 3-letter error code on the typewriter, sometimes followed by the S-expression in error. Except in the case of the <u>pce</u> and <u>sce</u> errors, the computation continues.

uas (unbound atomic symbol) - The argument of a call to <u>eval</u> is an atomic symbol with no value. The symbol in error is printed. <u>Nil</u> will be returned as the value of the call.

uaf (unbound atomic function) - A number without the subr or <u>fsubr</u> flag, or a symbol which is not bound or is bound to itself, has been used as a function. The number or symbol is printed. The arguments for the function will not be evaluated, and <u>nil</u> will be returned.

tfa (too few arguments) - A <u>subr</u> or <u>expr</u> has not been given enough arguments, or the symbol list after <u>nlamda</u> contains more than one symbol. <u>Nil</u> will be returned.

tma (too many arguments) - A <u>subr</u> or <u>expr</u> has been given too many arguments, or the symbol list after _nlamda_ is empty. _Nil_ will be returned.

cva (car of valueless atom) - an attempt has been made to calculate the _car_ of an atomic symbol which has no value. The symbol in error is printed, and _nil_ will be returned.

icd (illegal conditional) - A call to _cond_ has run out of propositions. _Nil_ will be returned.

ana (argument not atomic) - The argument to _prin1_ or _valp_ is not atomic. _Nil_ will be returned.

nna (non-numeric argument) - An argument to _plus_, _times_, _logor_, _logand_, _logxor_, _quotient_, _remainder_, _zerop_, or _greaterp_ is not a number. It will be taken as zero.

ovf (overflow) - The second argument for _quotient_ or _remainder_ is zero. Zero will be returned.

ilp (illegal parity) - A character from the tape reader has even parity. It will be ignored.

bsy (busy) - The reader, punch, or core 1 is busy. Type any character to try again.

pce (pushdown capacity exceeded) - The combined length of the pushdown list and symbol table is too great. LISP starts over at location zero. All temporary bindings remain.

sce (storage capacity exceeded) - The free-storage list has been exhausted, and no space could be reclaimed by the garbage collector. LISP starts over as with _pce_.

iif (illegal input format) - An object which is not an S-expression has been read. The entire call to _read_ will be started over.

Appendix - LISP functions

Column key: number of args; evaluate or quote; PF if pseudo-function; class.

name	type	number of args	evaluate or quote	PF if pseudo-function	class	description
car	subr	1	e		general	
cdr	subr	1	e		general	
caar	subr	1	e		general	car•car
cadr	subr	1	e		general	car•cdr
cdar	subr	1	e		general	cdr•car
cddr	subr	1	e		general	cdr∘cdr
cons	subr	2	e		general	
list	fsubr	n	e		general	
rplaca	subr	2	e	PF	general	y → (car x)
rplacd	subr	2	e	PF	general	y → (cdr x)
append	subr	2	e		general	
nconc	subr	2	e	PF	general	(append x y) → x
reverse	subr	1	e		general	
subst	subr	3	e		general	subst x for y in z
sassoc	subr	3	e		general	look up x in y, or call z
and	fsubr	n	e		logical	x and y and z ...
or	fsubr	n	e		logical	x or y or z ...
null	subr	1	e		predicate	x = nil
atom	subr	1	e		predicate	x is atom
numberp	subr	1	e		predicate	x is number
valp	subr	1	e		predicate	x is bound
zerop	subr	1	e		predicate	x = 0
greaterp	subr	2	e		predicate	x > y
eq	subr	2	e		predicate	x is y exactly
equal	subr	2	e		predicate	x looks like y
member	subr	2	e		predicate	x is a member of y

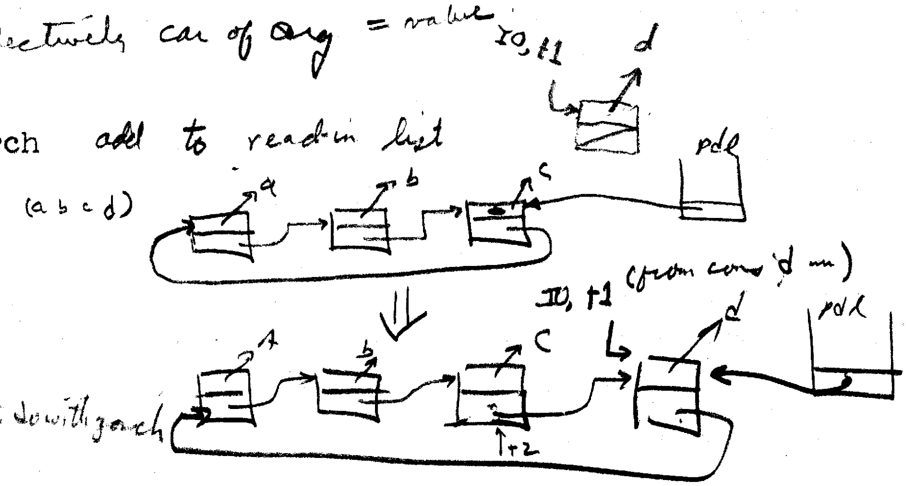
plus	fsubr	n	e		arith	x + y + z ...
minus	subr	1	e		arith	-x
times	fsubr	n	e		arith	x × y × z ...
logor	fsubr	n	e		arith	x ∨ y ∨ z ...
logand	fsubr	n	e		arith	x ∧ y ∧ z ...
logxor	fsubr	n	e		arith	x ~ y ~ z ...
quotient	subr	2	e		arith	[x/y]
remainder	subr	2	e		arith	x - y × [x/y]
read	subr	0		PF	I/O	
prin1	subr	1	e	PF	I/O	print atom
print	subr	1	e	PF	I/O	print S-expression
terpri	subr	0		PF	I/O	print carriage return
stop	subr	0		PF	I/O	wait
gensym	subr	0		PF	misc.	create symbol
quote	fsubr	1	q		misc.	
setq	fsubr	2	q,e	PF	misc.	bind x to y
cond	fsubr	n			misc.	
eval	subr	1	e		misc.	value of x
apply	subr	2	e		misc.	call x with y
trace	fsubr	n	q	PF	misc.	
untrace	fsubr	n	q	PF	misc.	
prindef	fsubr	n	q	PF	misc.	print definitions
dex	fsubr	3	q	PF	misc.	define expr
fix	fsubr	3	q	PF	misc.	fix x for y in z
prog	fsubr	n			misc.	
go	subr	1	e	PF	misc.	go to x
return	subr	1	e	PF	misc.	return from program
maplist	subr	2	e		misc.	send each element of x to y
prog2	subr	2	e		misc.	y

```
lisp for ts•1/1/66

test=sas hih

define error who,where
q=flexo who
jsp err'where
[q∧77×1]∨[q∧7700]∨[q∧770000×100]
terminate

ct=(1t
cn=(1nil
c1=(1
c3=(3
cpde=(pde

repeat 1-if2,equals halt,stop
bind=jdp bn
push=jda pwl
pop=jsp po
zorch=jdp zo

0/              jmp begin
                law rd1
                dap rdx
loop,           dzm pa3
                dzm pa4
                law pde
                dap pdl
                cal read
                cal eval
                cal print
                jmp loop

                lac 100
pwl,            0               /push
                dap psx
                law i 1
                adm pdl
                sad snd
                jmp pce
                lac pwl
                dac i pdl
psx,            jmp .

po,             dap pox         /pop
pdl,            lac pde
                dac pwl
                idx pdl
                lac pwl
pox,            jmp .
```

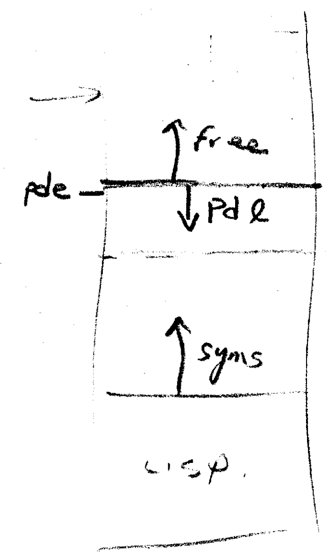
```
bn,t4,          0              /bind
                push  /name of atom
                lac i pwl
                dio i pwl /value to bind it to
                push /old value
                jmp i bn

cddr,           add (1                   /"cddr"
cdar,           cal car                  /"cdar"
cdr,            idx 100                  /"cdr"    100 points to arg
quote,                                   /"quote"
car,            lac i 100                /"car"    AC points to arg
                sza i                              i.e. 100
                jmp cva
x,              dac 100  ———  /main return routine
                pop
                ral 1s
                spa
                jmp pwl-1 /jmp
                lio pwl  /S-expression
                pop
                dio i pwl
                jmp x 1

cadr,           add (1                   /"cadr"
caar,           cal car                  /"caar"
                jmp car

number,         sma        numbers & atoms /"numberp"      AC has arg
        s expr ->jmp fal   have sign bit on
                sub cpde

atom,           sma                      /"atom"   atoms have sign bit on
                jmp fal  in free storage
tru,            lac ct  — point to T
                jmp x

zerop,          cal vag  — get value     /"zerop"
                sza
                jmp fal
                jmp tru

g4,t1,          0
g1,t2,          0

repeat ifm 100-.,[printx /No room.
/]
101/            dap pox
                sub (1
                dap . 1
                lac .
                dap . 4
                lac pox        /push return jmp
                push
                lac 100
                jmp .

cva,            error cva,-2
                jmp u2
```

must be a number   LISP3

```
vag,        sma
            jmp nna      - s expression
            sub cpde
            sma
            jmp nna      - in symbol table
            lac i 100    - effectively car of arg = value
            jmp x

zo,t3,      0                /zorch     add to read-in list
            idx i pdl
            dac t2
            idx t1
            lac i t2
            dac i t1
            dio i t2
            dio i pdl
            idx pwl      } nothing to do with zorch
            lac i pwl    }
            jmp i zo

valp,       sma                /"valp"
            jmp ana
            cla
            sas i 100
            jmp tru
fal,        lac cn       nil
            jmp x

ana,        error ana,-2
            jmp u2

nna,        error nna,-2
            cal print
nnx,        claVcliVstf 4
            jmp x
```



like {not [zerop]} with number or s expr



```
in,         stf 4
            szs 50
            jmp tin
ras,        skp 600     /skip if reader not assigned
            jmp ra2
            law 51
            jdp asg
            dap ras
ra2,        rpa
            rir 7s
            sni i
            spi
            jmp in
            ril 7s
            lai
            ior (rar
            dac . 2
            law 2525
            0
            spa
            jmp gtc
            error ilp
            jmp in

tin,        law i 51    /entry for stop
            xct ras
            arq         /dismiss reader
            law 600
            dap ras
            tyi
gtc,        lai
            and (77
            sas (74     /upper case
            sad (72     /lower case
            dac cas
            jmp x

asg,        0
            arq
            jmp bsy
            cla
            jmp i asg
bsy,        error bsy
            stf 4
            tyi
            law i 2
            adm asg
            jmp i asg

stop=.      cal tin               /"stop"
            jmp fal

cas,        72
```

```
             lac i a3
p3,          cal out
p2,          cal out

out,         law 77
             and 100
             sas cas
             sad (76
             jmp oux
             sad (77
ou4,         dac pcc
             ior (ral
             dac oug
             law 252
oug,         0
             and (200
             adm oug
             lia
             szs i 34
             jmp ou1
pas,         skp 600     /skip if punch not asigned
             jmp ou2
             law 47
             jdp asg
             dap pas
ou2,         lio oug
             ppa
             jmp ou3
ou1,         law i 47
             xct pas
             arq
             law 600
             dap pas
ou3,         szs i 64
             tyo
             law 77
             and 100
             sas (74
             sad (72
             jmp oux-1
             sas (56
             sad (40
             jmp oux
             law i 1
             adm pcc
             sma
             jmp oux
             law 77
             jmp ou4
             dac cas
oux,         lac 100
             rar 6s
             jmp x
pcc,         0
```

```
read,       clavstf 5           /"read"
            push
            lac pdl
            dap re2
            jmp rdx
iif,        error iif
re2,        law .     /old pdl
            dap pdl
            cal terpri
            stf 5
rd1,        clf 6     /on if letter seen
            clf 3     /on if minus sign seen
            dzm a1    /value of number
            lac snd
            dac sy2
            dac sy1
            dap pt1
            idx sy2
            sub pdl
            add (3
            sma
            jmp pce
            lac (add-7          /character count
            dac t2
            lio (767676
            dio i sy1
            dio i sy2
rlp,        cal in
            lio cas
            rir 2s
            law tb1   /lower case origin
            spi i
            law tb2   /upper case origin
            dap tbs
tb0,        law 77
            and i tbs
            sad 100
            jmp tbs
            idx tbs
            sas (lac tb3
            jmp tb0
            lac 100
            sub rad
            sma
            jmp rsl
num,        lac a1
            mul rad
            scr 1s
            lai
            lio 100
            rir 5s
            spi i
            add 100
            dac a1
            jmp rsl 1
min,        stf 3     /-
            jmp rsl 1
bsp,        lac i sy1 /backspace
            sad (767676
```

```
jmp re2
jmp rd1
```

```
tb1,        20+100xnum           /dispatch table
            54+100xmin
            55+100xrpr+add
            57+100xlpr+add
            73+100xper+add
            00+100xrd1+add
            33+100xrd1+add
            36+100xrd1+add
tb2,        56+100xvb
            75+100xbsp
            13+100xrlp
            77+100xrlp
tb3,vb,     cal in      /
rsl,        stf 6       /letter seen
            isp t2      /pack character
            jmp rlp
            sad (add-3
            idx pt1
pt1,        lac .
            lio 100
            rcr 6s
            dac i pt1
            jmp rlp
tbs,        lac .
            lia
            rar 6s
            dap rdx
            spi i
            jmp rdx
            law i 4000
            adm rdx
            lac i sy1
            sad (767676
rdx,        jmp .       /no atom
            szf 5 i
            jmp iif
            cal mka
            jmp rxy+2
putob,      law sym     /oblist lookup
            dap pt1
sy1,        lac .
            sas i pt1
            jmp id1-1
            idx pt1
sy2,        lac .
            sas i pt1
            jmp id1
fou,        idx pt1
            add (lac
            jmp x
            idx pt1
id1,        law 3
            adm pt1
            sas snd
            jmp sy1
            idx pt1
            dac snd
            idx snd
            dzm i snd
```

```
idx snd
lac cn
dac i snd
idx snd
jmp fou
```

```
lpr,        szf i 5    /(
            jmp iif
            lac cn
            push
            jmp rd1
per,        lac i pdl  /.
            sad cn
            jmp iif
            rar 1s
            spq 5
            jmp iif
            idx i pdl
            jmp rd1
rpr,        law rd1    /)
            dap rdx
            lac i pdl
            rar 1s
            spq
            jmp iif
            pop
            szf 5
            sad cn
            jmp rxy
            idx pwl
            lio cn
            lac i pwl
            dio i pwl
rxy,        stf 5
            dac 100
            pop
            sza i
            jmp x 1
            push
            rar 1s
            spa
            jmp rd5
            lac 100
            cal cons-1
            lac i pdl
            sad cn
            jmp rdn
            zorch
            jmp rdx
rdn,        idx t1
            dio i t1
            jmp rd7
rd5,        lio i pwl
            lac 100
            dac i pwl
            clf 5
rd7,        dio i pdl
            jmp rdx
mka,        sas (547676         /make atom
            szf 6
            jmp putob  /atomic symbol
            cal p10             /number
            szf 3
            cma
```

```
crn,        lio cn      /create number
            dio g1
            cal cons 1
            add (add
            jmp x

pce,        law pde
            dap pdl
            error pce
            jmp 0

fre,        0

snd,        lac esy

err-2,      lio 100
            dio a1
err,        dap erx
            clf 4
            cal terpri
            lac i erx
            cal p3
            cal terpri
            idx erx
            lac a1
erx,        jmp .
```

```
prin1,     sma                     /"prin1"
           jmp ana
           sub cpde
           sma
           jmp prs       /symbol
           lac i 100
           lia
           spa
           cma
           dac a3
           dzm t3
           law 54
           spi
           cal out
dpl,       lac a3
           dac t4
           mul (1
           div rad
rad,       10.
           sas t3
           jmp dpl 1
           lai
           sza i
           law 20
           cal out
           lac t4
           dac t3
           sas a3
           jmp dpl
           jmp p10

prs,       law i 2
           add 100
           dac a3
           cal p3-1
           idx a3
           cal p3-1
p10,       law 10.
           szs 40
           law 10
           dac rad
           lac a1
           jmp x
```

number printer

symbol print

```
          cal print
terpri,   law 7772            /"terpri"
          cal p2
          jmp fal

print,    dac t1              /"print"
          cal terpri
          cla
          push
          lac t1
pn1,      spa
          jmp pn2  — got atom to print
          law 5772   is expression
pn5,      cal p2
          lac t1
          cal cdr
          push
          lac i t1  get the car
          dac t1
          jmp pn1
pn2,      cal prin1 2
pn6,      pop
          dac t1
          sza i
          jmp pn7 — done
          law 72
          lio t1
          spi i
          jmp pn5
          lac t1
          sad cn
          jmp pn3
          law 7372
          cal p2
          lac t1
          cal prin1 2
pn3,      law 5572  )
          cal p2
          jmp pn6
pn7,      law 72
          cal p2
          lac a1  jmp p10-4
          jmp x
```

```
cons-2,     cal eval-1
cons-1,     lio cn
cons,       dzm g1              /"cons"  (cons a, b)
            lac fre
            sza i
            jmp gc              /garbage collect
con2,       dac t1
            lac 100
            dac i fre
            idx fre
            lac i fre
            dio i fre
            dac fre
            lac t1
            lia
            jmp x

null=.      xor cn              /"null"
            jmp zerop 1

setq,       push                /"setq"   (setq a b)
            cal eval-2
            lia
            pop
            cal car
            dio i 100
            jmp prog2

rplacd,     idx 100             /"rplacd"   (replacd a. b)
            sub (1

rplaca,     dio i 100           /"rplaca"
            jmp x

evlis-1,    lac a2
evlis,
list,       szf 2               /"list"
            sad cn
            jmp x
            push
            cal cons-2
            lac i pdl
            dac pwl
            dio i pdl
            jmp el2
ele,        push
            cal cons-2
            pop
el2,        zorch
            sas cn
            jmp ele
            lio cn
el5,        pop
            idx pwl
            lac i pwl
            dio i pwl
            jmp x
```

Handwritten annotations: cons — "AC=a, IO=b", "+1, AC⇄IO"; con2 dac t1 — "value of the cons"; setq — "(eval b)", "lia → value [b]", "car get → a", "car of the atom is the value", "AC → a"; rplacd — "AC=a, IO=b", "leaves with AC=a, IO=b"; list — "Flag 2 = 0 → nop", "AC = list", "(list a b c d)", "sad cn nil", "jmp x at end", "cal cons-2 evaluate first arg and cons with nil", "dio i pdl point PDL at the first element of the list being created", "ele push / cal cons-2 evaluate arg and cons with nil", "zorch q.v. add to tail of list", "jmp ele get next element", "el5 pop point to last element of list", "lac i pwl pointer to head of created list", "dio i pwl put nil at end of list."

```
gfr,        dap gfx     /list marker
            lac i pt1
            ral 1s
            spq
            jmp gfx
            law i 1
            and i pt1
            cliVswp
in1,        dac g1
in2,        dac g3
            idx g3
in3,        dio g2
            dio g4
            idx g4
            lac i g4
            and (dip
            sza i
            jmp gcn
            lac g1
            sza i
gfx,        jmp .
            lac i g3
            ral 1s
            spa
            jmp gcb
            lac i g3
            and (-dip
            lia
            lac i g1
            ior (dip
            dac i g3
            lac g2
            dac i g1
            jmp in3
gcb,        lio g1
            lac i g3
            and (-dip
            dac g1
            lac g2
            ior (lac
            dac i g3
            lac g1
            jmp in2

gcn,        lac g2
            sma
            jmp gcl
            sub cpde
            sma
            jmp gfx-2
            lio i g4
            lac g1
            ior (dip
            dac i g4
in4,        lac g2
            jmp in1
gcl,        lio i g2
            lac (xct
            adm i g4
```

```
lac g1
dac i g2
jmp in4
```

```
gc,     dio a1        /garbage collector
        clcVlia
        dpy 400
        law 100
        dap pt1
        lac g1
        sza i
        jsp gfr
        law sym
        dap pt1
oblp,   law 2
        adm pt1
        jsp gfr
        idx pt1
        jsp gfr
        idx pt1
        sas snd
        jmp oblp
        lac pdl
        dap pt1
pdlp,   jsp gfr
        idx pt1
        sas el1       />lac a2
        jmp pdlp
low,    law frs
        dac t1
swlp,   idx t1
        lac i t1
        lia
        and (-lac
        dac i t1
        ril 1s
        spi
        jmp swlf
        lac fre
        dac i t1
        law i 1
        add t1
        dac fre
swlf,   idx t1
        test
        jmp swlp
        claVcli
        dpy 300
        lio a1
        lac fre
        sza
        jmp con2
        error sce
        jmp 0
```

```
prog2,      lai                     /"prog2"
            jmp x

return,     dac pa3                 /"return"
go,         dac pa4                 /"go"
            jmp x

prog,       lac i a1                /"prog"
            sad cn
            jmp pr2
            dac 100     /get a prog variable
            lac i 100
            lio cn
            bind
            lac 100
            cal cdr
            jmp prog 1

pr2,        lac a1
pr3,        cal cdr

            sad cn
            jmp pr35
            lia
            cal car
            spa
            bind
            lai
            jmp pr3

pr35,       lac pa3
            push
            lac pa4
            push
            dzm pa3
            lac a1
pr4,        cal cdr
            dac pa4
            sad cn
            jmp pr6     /program finished
            lac i pa4
            cal eval
ik2,        lac pa4
            lio pa3
            sni
            jmp pr4
            lai

pr6,        dac 100
            pop
            dac pa4
            pop
            dac pa3
            jmp x 1
```

```
apply,      clf 2                   /"apply"
            jmp apl

ikd,        pop
            sad . 1
            jmp ik2
            push
            error icd
            jmp tfa 2
cn2,        pop
            cal cdr    get next (pi ei) pair
cond,       sad cn                  /"cond"
            jmp ikd
            push
            cal caar   get pi
            cal eval
            sad cn
            jmp cn2    move on
            pop
            cal car
eval-2,     cal cdr    evaluate resulting ei
eval-1,     cal car
eval,       dac a1                  /"eval"
            sma
            jmp ev2     /not atomic
            sub cpde
            spa
            jmp x 1     /number
            lac i a1    /atomic symbol
            sza
            jmp x
            error uas
u2,         cal terpri-1
            jmp tfa 2
ev2,        lio i a1
            cal cdr
            dac a2      /argument list
            stf 2       come from eval not apply
            dio a1      /function
apl,        lac a1
            sma
            jmp e3      /non-atomic function
            sub cpde    /atomic function
            sma
            jmp e4      /symbol
            lac a1      /number
            cal cdr
            sad (1subr
            jmp esu
            sas (1fsubr
            jmp uaf
            lac i a1    /function is fsubr
            dap exs
            lac a2
            dac a1
exg,        lio a2
            dac 100
exs,        jmp .
```

```
esu,        lac i a1   /function is subr
            push
            cal evlis-1
            pop
            dap exs
            ral 6s
            and (3
            add (a1
            dac t2
            law a1
            dac t1
sp1,        sad t2
            jmp sp9
            lac 100
            sad cn
            jmp tfa
            lac i 100
            dac i t1
            lac 100
            cal cdr
            idx t1
            jmp sp1
sp9,        lac 100
            sas cn
            jmp tma
            lac a1
            jmp exg

e4,         lac i a1   /function is symbol
            sza
            sad a1
            jmp uaf
            dac a1
            jmp apl

uaf,        error uaf
            jmp u2

e3,         lac i a1   /function is not atomic
            sad (1lambda
            jmp ela
            sad (1nlamda
            jmp enl
            sad (1label
            jmp elb
            lac a2     /evaluate entire function
            push
            lac a1
            cal eval
            pop
            lio 100
            jmp apl-3
```

```
ela,            lac a1       /function is "lambda"
                push
                cal evlis-1
                dac a2
                pop
                dac a1       /args in a2,function in a1
                cal cadr     /get lambda variables
/pair lambda list with arg list
el1,            lac a2
                sad cn
                jmp el9      /no more args
                lac 100
                sad cn
                jmp tma
                lac i 100
                lio i a2
                bind
                idx a2
                lac i a2
                dac a2
                lac 100
                cal cdr
                jmp el1
el9,            lac 100
                sas cn
                jmp tfa
                lac a1
                cal cddr
                jmp eval-1

enl,            lac a1       /function is "nlamda"
                cal cadr
                sad cn
                jmp tma
                lac i 100
                lio a2
                bind
                idx 100
                lac i 100
                jmp el9 1

elb,            lac a1       /function is "label"
                cal cdr
                dac a1
                cal cadr
                lia
                lac i a1
                bind
                jmp apl-1

tfa,            error tfa
                stf 4
                jmp fal

tma,            error tma
                jmp tfa 2

constants
```

```
define here x,y
x
y
terminate

define put z
here [define here 123,456
123],[z
456
terminate]
terminate

define páck q
n2=q
n1=767676
repeat 3,n2=n2×100      repeat ifn n2∧77,n1=n2~n1∧77~n1×i
n1
terminate

define pname name,val
pack text1 /name/
pack text2 /name/
1'name=add .
val         1nil
terminate

define su name,num,/g
pname name,add g
put [s name,num,g]
terminate

define fsu name,/g
pname name,add g
put [f name,g]
terminate

define apval name
pname name,1'name
terminate

define thing name
pname name,0
terminate

equals s,if2
equals f,if2
repeat 1-if2,define kill x         terminate
repeat if2,define kill x           equals x,if2     terminate

hih,        i

.+.∧1/

sym,
```

LISP 21

```
su cons,2
fsu quote
su car,1
su cdr,1
su caar,1
su cadr,1
su cdar,1
su cddr,1
su null,1
su rplacd,2
su rplaca,2
fsu setq
fsu prog
su go,1
su return,1
apval t
apval nil
su zerop,1
thing lambda
thing nlamda
thing label
fsu cond
su apply,2
su eval,1
fsu list
su terpri,0
su valp,1
su number,1
su atom,1
su prog2,2
su read,0
su prin1,1
su print,1
su stop,0
thing subr
thing fsubr
su eq,2
su equal,2
su minus,1
fsu plus
fsu times
fsu logand
fsu logor
fsu logxor
su greate,2
su remain,2
su quotie,2
fsu and
fsu or
su maplis,2
su append,2
su nconc,2
su member,2
su gensym,0
su sassoc,3

fsu prinde
fsu dex
su subst,3
```

LISP2 2

```
fsu fix
su revers,1
fsu trace
tsy,
fsu untrac
thing 99g
thing enter
thing value
```

LISP 24

```
esy,
/free storage maker

begin,      eem
            lio .-1
            dio 0
            szs 20 i
            jmp . 5
            lac (and
            dac hih
            law 6301
            jdp asg
            clf 4
            szs 10 i
            jmp nxp
xpl,        lac (lac-2
            add a2
            dac a1
            cal print
            tyi
            lai
            sas (charac rx
            jmp nxp
            law i 4
            adm a2
            dac snd
            lac i a1
            dap ta5
            sma
            jmp xpl
            lac i ta5
            add (1
            and (-1
            dap low
            jmp xpl
nxp,        cli
            xct low
gc9,        sad (frs
ta5,        law fr2
            dac t1
            dac g1
            idx t1
            dio i t1
            lio g1
            idx t1
            test
            jmp gc9
            dio fre
            jmp 0
constants
sym 2100/
pde,
pa3,        0
pa4,        0
a1,         0
a2,g3,      lac tsy
a3,g2,      0
```

```
eq,         xor a2                /"eq"
            jmp zerop 1

eq4,        pop
            cal cdr
            lia
            pop
            cal cdr

equal,      dio t1                /"equal"
            sad t1
            jmp tru
            spaVspi
            jmp eq3
            sma
            spi
            jmp fal
            push
            lai
            push
            lac i 100
            lio i pwl
            cal equal
            sas cn
            jmp eq4
            pop
ppf,        pop
            jmp fal

eq3,        sub cpde
            swp
            sub cpde
            spaVspi i
            jmp fal
            lac i 100
            xor i t1
            jmp zerop 1

minus,      cal vag               /"minus"
            jmp crn-1

plus,       cal evlis             /"plus"
            law cadt2

            dzm t2
nmop,       dap nm2
            lac 100
nm1,        dac a2
            sad cn
            jmp nm9
            lac i a2
            cal vag
nm2,        xct .
            dac t2
nm3,        lac a2
            cal cdr
            jmp nm1
nm9,        lac t2
            jmp crn
```

```
cadt2,      add t2
```

```
times,      cal evlis        /"times"
            law 1
            dac t2
            jsp nmop
            jmp . 1
            mul t2
            scr 1s
            dio t2
            adm t2
            jmp nm3

logand,     cal evlis        /"logand"
            clc
            dac t2
            jsp nmop
            and t2

logor,      cal evlis        /"logor"
            jsp nmop-1
            ior t2

logxor,     cal evlis        /"logxor"
            jsp nmop-1
            xor t2

greate,     cal vag          /"greaterp"
            dac a1
            lac a2
            cal vag
            clo
            sub a1
            szo
            lac 100
            jmp atom

remain,     cal divi         /"remainder"
            swp
            jmp crn

divi,       lai
            cal vag
            dac a2
            lac a1
            cal vag
            mul c1
            div a2
            jmp . 2
            jmp x
            error ovf
            jmp nnx

quotie,     cal divi         /"quotient"
            jmp crn
```

```
and2,       sad cn              /"and"
            jmp tru
            push
            cal eval-1
            sad cn
            jmp ppf
            pop
            cal cdr
            jmp and2

or1,        pop
            cal cdr

or,         sad cn              /"or"
            jmp fal
            push
            cal eval-1
            sad cn
            jmp or1
ppt,        pop
            jmp tru

maplis,     sad cn              /"maplist"
            jmp x
            push
            cal map
            lac i pdl
            dac pwl
            dio i pdl
            jmp mp2
mp1,        push
            cal map
            pop
mp2,        zorch
            sas cn
            jmp mp1
            jmp e15-1
map,        lac a2
            push
            lac i 100
            cal cons-1
            lac a2
            dac a1
            dio a2
            cal apply
            cal cons-1
            pop
            dac a2
            jmp x
```

```
append,     sad cn                /"append"
            jmp prog2
            push
            cal car
            cal cons
            lac i pdl
            dac pwl
            dio i pdl
            jmp apn2
apn1,       push
            cal car
            lio a2
            cal cons
            pop
apn2,       zorch
            sas cn
            jmp apn1
            lio a2
            jmp e15

nconc,      sad cn                /"nconc"
            jmp prog2
            dac a2
            cal cdr
            sas cn
            jmp .-3
            idx a2
            dio i a2
            lac a1
            jmp x

member,     lai                   /"member"
            sad cn
            jmp fal
            dac a2
            lac i a2
            lio a1
            cal equal
            sas cn
            jmp x
            lac a2
            cal cdr
            jmp member 1
```

```
gensym,     law gst                 /"gensym"
            dac t1
gen2,       idx i t1
            sad (21
            law 1
            dac i t1
            sas (12
            jmp gen3
            law 20
            dac i t1
            idx t1
            jmp gen2
gen3,       lac snd
            dac sy2
            dac sy1
            idx sy2
            sub pdl
            add c3
            sma
            jmp pce
            law charac mg
            ior gst 3
            ral 6s
            ior gst 4
            ral 6s
            dac i sy1
            lac gst
            ral 6s
            ior gst 1
            ral 6s
            ior gst 2
            dac i sy2
            jmp putob

constants

gst,        repeat 5,20

sassoc,     lac a2                  /"sassoc"
            sad cn
            jmp ss2
            cal car
            lac i 100
            sad a1
            jmp x 1
            lac a2
            cal cdr
            dac a2
            jmp sassoc 1
ss2,        lio a3
            lac cn
            jmp ev2 2
```

```
prinde,     sad cn              /"prindef"
            jmp pf1
            push
            cal caar
            cal cons-1
            lac pq
            cal cons
            cal cons-1
            lac i pdl
            cal car
            swp
            push
            swp
            cal cons-1
            lac pq
            cal cons
            pop
            swp
            cal cons
            lac (1rplaca
            cal cons
            cal terpri-1
            pop
            cal cdr
            jmp prinde
pq,         1quote
pf1,        lac (1stop
            dac 100
            jmp cons-1

constants

dex,        cal cdr             /"dex"
            lia
            lac i a1
            dac a1
            lac lam
            cal cons
            dio i a1
            jmp pn7 2
lam,        1lambda
```

```
subst,      push                    /"subst"
            lai
            push
            cal subs1
            pop
            pop
            jmp x 1

subs1,      lio a2
            lac a3
            cal equal
            sad cn
            jmp . 3
            lac a1
            jmp x
            lac a3
            spa
            jmp x
            cal cdr
            push
            lac i a3
            dac a3
            cal subs1
            lio i pdl
            dac i pdl
            dio a3
            cal subs1
            lia
            pop
            dac 100
            jmp cons

fix,        cal cdr                 /"fix"
            lio i 100
            dio a2
            cal cadr
            push
            cal car
            dac a3
            lac i a1
            dac a1
            cal subst
            lia
            pop
            dio i pwl
            jmp x

revers,     lio cn                  /"reverse"
            sad cn
            jmp prog2
            push
            cal car
            cal cons
            pop
            cal cdr
            jmp reverse 1
```

```
trace,      sad cn                    /"trace"
            jmp tru
            push
            lac i pwl
            dac t3
            lac i t3
            sza i
            jmp tr2
            cal car
            sas lam
            jmp tr2
            lac (199g
            cal cons-1
            dac t4
            lac (1print
            cal cons
            cal cons-1
            lac (1return
            cal cons
            cal cons-1
            lio i pdl
            push
            lai
            cal car
            cal cons-1
            lac (1value
            cal cons
            cal cons-1
            lac pq
            cal cons
            cal cons-1
            lac (1print
            cal cons
            lio i pdl
            cal cons
            dio i pdl
            lac i t3
            cal cddr
            cal car
            cal cons-1
            lac (199g
            cal cons
            lac (1setq
            cal cons
            lio i pdl
            cal cons
            dio i pdl
            lac i t3
            cal cadr
            lia
            lac (1list
            cal cons
```

4 15 Y 3 4

```
              cal cons-1
              lac (1print
              cal cons
              lio i pdl
              cal cons
              dio i pdl
              lac t3
              cal cons-1
              lac (1enter
              cal cons
              cal cons-1
              lac pq
              cal cons
              cal cons-1
              lac (1print
              cal cons
              lio i pdl
              cal cons
              lac t4
              cal cons
              lac (1prog
              cal cons
              lac i t3
              cal cddr
              dio i 100
              idx pdl
tr2,          pop
              cal cdr
              jmp trace

untrac,       sad cn                  /"untrace"
              jmp tru
              cal car
              lac i 100
              sza i
              jmp ut2
              cal cddr
              dac t2
              cal cdar
              dac t1
              cal caar
              sas (199g
              jmp ut2
              lac t1
              cal cddr
              cal cadr
              cal cddr
              cal car
              dac i t2
ut2,          lac a1
              cal cdr
              dac a1
              jmp untrac

constants
```

```
.+.Λ1/
frs,
and=and2

equals put,if2
equals pname,if2
equals su,if2
equals fsu,if2
equals apval,if2
equals thing,if2

define s name,num,g
g,jmp ixnum name
1subr
kill g
terminate

define f name,g
g,jmp name
1fsubr
kill g
terminate

here
and=i i
fr2,
equals n1,if2
equals n2,if2
equals n3,if2
equals q,if2
start
```

LISP 3C

```
(rplaca (quote theore) (quote (lambda (s) (and (null (atom s))
(th nil nil nil (list s))))))

(rplaca (quote caddr) (quote (lambda (s) (car (cddr s)))))

(rplaca (quote th) (quote (lambda (a1 a2 c1 c2) (cond ((null a2
) (and (null (null c2)) (thr (car c2) a1 a2 c1 (cdr c2)))) (t (
th1 (car a2) a1 (cdr a2) c1 c2))))))

(rplaca (quote th1) (quote (lambda (u a1 a2 c1 c2) (cond ((eq (
car u) (quote not)) (th1r (cadr u) a1 a2 c1 c2)) ((eq (car u) (
quote and)) (th21 (cdr u) a1 a2 c1 c2)) ((eq (car u) (quote or)
) (and (th11 (cadr u) a1 a2 c1 c2) (th11 (caddr u) a1 a2 c1 c2)
)) ((eq (car u) (quote implie)) (and (th11 (caddr u) a1 a2 c1 c
2) (th1r (cadr u) a1 a2 c1 c2))) ((eq (car u) (quote equiv)) (a
nd (th21 (cdr u) a1 a2 c1 c2) (th2r (cdr u) a1 a2 c1 c2)))))))


(rplaca (quote thr) (quote (lambda (u a1 a2 c1 c2) (cond ((eq (
car u) (quote not)) (th11 (cadr u) a1 a2 c1 c2)) ((eq (car u) (
quote and)) (and (th1r (cadr u) a1 a2 c1 c2) (th1r (caddr u) a1
 a2 c1 c2))) ((eq (car u) (quote or)) (th2r (cdr u) a1 a2 c1 c2
)) ((eq (car u) (quote implie)) (th11 (cadr u) (caddr u) a1 a2
c1 c2)) ((eq (car u) (quote equiv)) (and (th11 (cadr u) (caddr
u) a1 a2 c1 c2) (th11 (caddr u) (cadr u) a1 a2 c1 c2)))))))

(rplaca (quote th1l) (quote (lambda (v a1 a2 c1 c2) (cond ((ato
m v) (or (member v c1) (th (cons v a1) a2 c1 c2))) (t (or (memb
er v c2) (th a1 (cons v a2) c1 c2)))))))

(rplaca (quote th1r) (quote (lambda (v a1 a2 c1 c2) (cond ((ato
m v) (or (member v a1) (th a1 a2 (cons v c1) c2))) (t (or (memb
er v a2) (th a1 a2 c1 (cons v c2))))))))

(rplaca (quote th2l) (quote (lambda (v a1 a2 c1 c2) (cond ((ato
m (car v)) (or (member (car v) c1) (th11 (cadr v) (cons (car v)
 a1) a2 c1 c2))) (t (or (member (car v) c2) (th11 (cadr v) a1 (
cons (car v) a2) c1 c2)))))))

(rplaca (quote th2r) (quote (lambda (v a1 a2 c1 c2) (cond ((ato
m (car v)) (or (member (car v) a1) (th1r (cadr v) a1 a2 (cons (
car v) c1) c2))) (t (or (member (car v) a2) (th1r (cadr v) a1 a
2 c1 (cons (car v) c2))))))))

(rplaca (quote th11) (quote (lambda (v1 v2 a1 a2 c1 c2) (cond (
(atom v1) (or (member v1 c1) (th1r v2 (cons v1 a1) a2 c1 c2)))
(t (or (member v1 c2) (th1r v2 a1 (cons v1 a2) c1 c2)))))))

(stop)
```

```
(rplaca (quote thing) (quote (equiv (and (and (equiv p q) (or s
 (not r))) (equiv r q)) (or (or (and (and p q) (and r s)) (and
(and (not p) (not q)) (and (not r) (not s)))) (and (and (not p)
 (not q)) (and (not r) s))))))

(stop)
```