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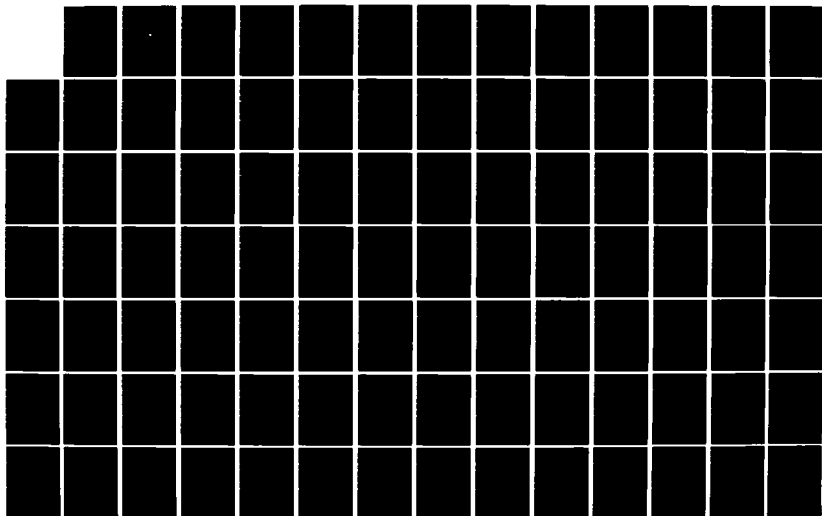
A PASCAL INTERPRETER FOR THE FUNCTIONAL PROGRAMMING
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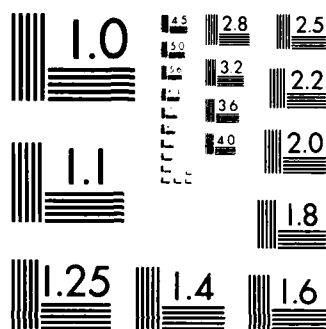
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THESIS

A PASCAL INTERPRETER FOR THE FUNCTIONAL
PROGRAMMING LANGUAGE ELC

by

Ralph P. Steen, Jr.
December 1984

Thesis Advisor:

Bruce J. MacLennan

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A Pascal Interpreter for the
Functional Programming Language ELC

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Functional programming is a methodology designed to eliminate many of the problems of past programming languages through actions such as the elimination of the assignment statement and the ability to program in an environment that is at a higher level of abstraction than any previous languages. In this report an interpreter, written in Pascal, for the Extended Lambda Calculus is presented. Initially, the events leading to the development of functional programming is discussed followed by an in depth look at how the interpreter operates. Numerous example ELC programs are presented, including discussions of practical applications and statistical information about execution times and memory requirements. The Berkeley Pascal source code for the interpreter is also included in Appendix C.

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I. PURPOSE AND BACKGROUND

A. PURPOSE

The purpose of this thesis is to illustrate the design and use of an interpreter for the Extended Lambda Calculus (ELC) as described by MacLennan [Ref. 1]. Initially, however, it is important to understand why functional languages such as ELC are important and why they will become increasingly important in the future. To achieve this, a brief background sketch is presented to explain the events that have shaped the need for such languages.

B. BACKGROUND

During the brief history of Computer Science there has been a remarkably rapid evolution of computing hardware, while software development has for all practical purposes remained static. Throughout the last thirty years, improvements such as: decreasing component size, increased memory capacity, faster processor speeds and reduced hardware costs have occurred at regular intervals. This trend continues today in areas such as super computers like the Cray and Cyber and the rapidly changing micro computer industry. If one studies the evolution of computer software for the same time period, in particular programming languages, the same types of rapid improvements on a regular basis have not occurred. The first revolutionary development in programming languages occurred with the development of FORTRAN by Backus et al. in the mid 1950s. For the first time scientific programmers could write code that strongly resembled the equations they were working with. Practically all the programming languages developed since that time, perhaps

with the exception of LISP and APL, are basically the same underneath as Fortran. Of course there are some outward differences, such as sophisticated string and array handling mechanisms, but they are all sequentially processed and rely heavily on use of the assignment statement, variables and the notion of machine state. The early pioneers in programming languages are not totally at fault for the lack of progress. To understand this statement, a brief examination of the architecture these languages were written for is necessary.

The great improvements in hardware development, mentioned previously, were also not fundamental until fairly recently. Hardware improvements remained superficial in that the majority of them were made on the same architecture, that proposed by von Neumann et al. in 1946. Briefly, the von Neumann architecture consists of a Central Processing Unit, a Memory used to store both programs and data, and some kind of connection between the two capable of transmitting single words or addresses back and forth. Improvements have concentrated on decreasing size, increasing speed, etc. and have not been concerned about the basic design of the computer. The connection between the memory and the CPU is the reason why most programming languages are sequential in nature, forcing the user to deal with some fairly low level constructs such as incrementing counters and setting up iteration loops. Backus [Ref. 2] termed this connection the von Neumann bottleneck and also described conventional programming languages as just software versions of von Neumann machines. Computer architectures are starting to change, however, and in order to gain the maximum benefit from these programming languages and techniques must change also.

Throughout the development of new hardware systems the trend has been to increase speed by making components

smaller and smaller. Common sense dictates that eventually the ability to do this will become physically impossible. Does this mean that the quest to increase computation speed will stop? Obviously not. The most promising solution is to fully exploit parallel operations in data processing whenever possible. As explained by Stone [Ref. 3], much promising work has been accomplished in the fields of array, multiprocessor, and pipeline computers, but there are still open research problems concerning how to properly organize and synchronize all these processors. In other words there is no effective software to manage parallel computer operations. Conventional programming languages, with their sequential nature, do not offer much hope as a solution. The functional programming languages, such as FP proposed by Backus [Ref. 2], or the Kent Recursive Calculator by Turner [Ref. 4], by their very nature lend themselves to parallel operations. This is illustrated in the next section.

As stated previously, one of the biggest problems with conventional languages is the assignment statement. Backus [Ref. 2] calls the assignment statement the bottleneck of programming languages because at the heart of all conventional programs we find a myriad of assignment operations producing one word results. The programmer must then concern himself with the flow of words through these assignment statements to achieve the desired results, instead of concerning himself with the problem as a whole. Another problem with the assignment statement is that it makes programs unreliable. Mathematical proofs do not lend themselves well to statements. Consider someone trying to do a mathematical proof of the following statement.

$$x := x+1$$

That statement makes absolutely no sense mathematically. How can 'x' be assigned the value of itself plus one? This statement is legal, however, in most conventional

programming languages and makes formal proofs of them extremely difficult as shown by the work of Hoare [Ref. 5]. Functional languages do away with the idea of the assignment statement and work only with expressions. Expressions, in contrast with statements, do possess mathematical properties. Backus [Ref. 2] has even shown that the functional language FP lends itself to an algebra of programs that can allow for relatively simple proofs of program correctness. Since functional languages deal only with expressions, the idea of execution order becomes obsolete, as explained by MacLennan [Ref. 6]. One begins to understand how these languages can be used to exploit parallelism since several expressions could be solved simultaneously and then brought together to form a final result.

Another advantage of functional programming is the compactness of the code written by programmers. Two examples from the literature illustrate this fact very well. Backus shows in [Ref. 2] an FP program to calculate the factorial of an arbitrary integer n . The program is one line long, whereas the corresponding program written in PL/I is eight lines long. The two programs are shown in Figure 1.1 for comparison. An even more startling example was devised by Early [Ref. 7], where a two pass assembler was written in both FP and C for an artificial assembly language. The assembler written in C occupied 459 lines of non-comment source code, whereas the FP assembler occupied 249 lines, of which more than 100 lines were only a single character so as to aid in program readability and clarity. This fact could have far reaching effects in an attempt to solve the software crisis as presented by Turner [Ref. 4]. The fact that the code is more compact could mean increased programmer productivity since it is well known that programming time is roughly proportional to the number of lines of code regardless of the language being used. Also, since it

```
memb <2> <1 2 3> = false
memb <a b> <z t s <a b>> = true
```

E. THE HEART OF THE INTERPRETER, THE EVAL FUNCTION

The eval function, Figure 2.6, is the most important function in the interpreter. Eval acts as a decoder, determining how each list sent to it is to be interpreted. This is accomplished by stripping off the first element of the list or program and then invoking a rule that corresponds to that first element. For example, if the program is

```
<list a b c>
```

eval will strip off the word "list" and return <a b c> as the result. Referring back to the line of code that starts program execution, it is seen that after the program is read in it is sent to the eval function along with a pointer called primitives. Primitives is a pointer to an association list which acts as an environment for executing the primitive operations discussed in the last section. For a detailed discussion of association lists and environments see MacLennan [Ref. 6]. The primitives association list is built initially by using the dcprim (declare primitives) function. An example of a part of the list is shown in Figure 2.7. The reason this primitives association list is constructed is to maintain consistency between how primitive and user defined functions are evaluated by the interpreter. This is discussed in more detail later in the next section.

It is important to now look at the key words recognized by eval and the rules they invoke. By doing this, a complete understanding of the interpreter will be achieved.

1. Function Eval's Keywords

- list 'List' simply lets the interpreter know that this expression is a list, so eval returns the rest of the list sent to it. For example, if eval is sent

- Sub Returns a particular element from a list. Takes two arguments: a pointer to a list and an integer indicating the position of the desired element in a list. For example, `sub (<A B C> 2) = B`
- Repr Takes a finite set (finset) as an argument and returns its ELC representation, which is simply a list.
`repr <finset a b c 1 2> = <a b c 1 2>`
- Len Determines the length of any list.
`len <a> = 1`
`len <> = 0`
`len <a <b c> d> = 3`
- Equal Equal tests the equality of any two atoms or any two lists.
`equal <2 2> = true`
`equal <a c> = false`
`equal <a b c> <a b c> = true`
`equal <a b c> <a <b> c> = false`
- GT Greater-than tests if arg1 is greater than arg2.
`GT arg1 arg2 = true/false`
`GT 2 3 = false`
`GT 5 1 = true`

The next three boolean primitives follow the same pattern as GT.

- LT Less-than
- GE Greater-than or equal to
- LE Less-than or equal to
- Memb Member tests to see if arg1 is an element of arg2, which must be a list.
`memb arg1 <arg2> = true/false`
`memb 2 <1 2 3> = true`

```

conr a <b c> = <b c a>
conr <a b> <c d> = <c d <a b>>

```

- Atom A Boolean function that determines if its argument is an atom.

```

atom 'a' = true
atom <list a b c> = false

```

- Null A Boolean function to determine if a list contains no elements. The last example is a list containing one element which happens to be a null list.

```

null <> = true
null <a> = false
null <<>> = false

```

- Binary Arithmetic Operators Each of the listed operators works for any m,n where m,n are two integers or two real numbers.

```

sum m n
subt m n
prod m n
divi m n

```

- Trigonometric Functions The following functions take single arguments of angles in degrees.

```

sin x
cos x
tan x
cot x
sec x
csc x

```

- Id Identity Function; simply returns the argument it is sent, eg. id 2 = 2 and id 'a' = 'a'. The purpose of this function is illustrated in example program x Appendix B which generates the table of sin, cos, tan for all angles from 0 to 90 degrees.

description of the primitive cons is covered in Section 3 of this chapter, but suffice it to say that cons forms the first element of the list represented as a cell pointed to by the head of a 1st cell with the tail set to nil. Additional cells are added by connecting them properly to the tail of the last cell read using the cons primitive and manual manipulation of pointers. This is accomplished by the while loop in function readlist. This process continues until a right angle bracket is recognized, which of course signifies the end of a list.

3. Primitive Operations

The following are the primitive operations provided by the interpreter and a brief explanation of each. Correct syntax for the language is covered in Appendix A.

- First Takes a list and returns the first element, eg. the first of <a b c> is a.
- Rest Takes a list and returns a list containing everything but the first element, e.g., the rest of <a <b c d> e> is <<b c d> e>.
- Last Takes a list and returns the last element, e.g., the last of <a b c> is c.
- Initial Takes a list and returns all elements except the last, e.g., the initial of <a b c> is <a b>.
- Cons Takes an atom or list and makes it the first element of a second list. The second argument of a cons operation must be a list.

cons a <b c> = <a b c>

cons <a b> <c d> = <<a b> c d>

- Conr Cons to the right. Conr is the opposite of the cons operation in that it makes an atom or list the last element of a second list.

number of 1st cells that are at the top of the Figure, there are three with the tail field of the 1st cell at the far right set to nil. Being consistent with the previous discussion this is a list containing three elements. The head of the second 1st cell, however, does not point to a leaf or information cell, it points to another 1st cell which forms the identical structure as previously seen. Again, the tail field of the last element in the internal list is nil, signifying the end of this list.

D. ELC PROGRAMS

1. Definition

An ELC program is nothing more than a list built in such a way that it can be evaluated by the interpreter. It is important to remember that one program equals one list. Of course this one list usually consists of many other nested lists as its elements.

2. Reading Programs

Programs are read into the interpreter by the readval and readlist functions, which can be reviewed in Appendix C, Source Code. The reading process is started by the following line of the interpreter.

```
printval (eval( readval, primitives))
```

The first function called is the readval function which determines the type of data being read by recognizing the first character of the input. Since a program is a list, the first character will obviously be a left angle bracket '<', transferring execution to the readlist function. Readlist builds the program into the same kind of structure as discussed in the last section. This is seen by first noticing that readlist calls readval again and the results are placed in a list through the cons function. A detailed

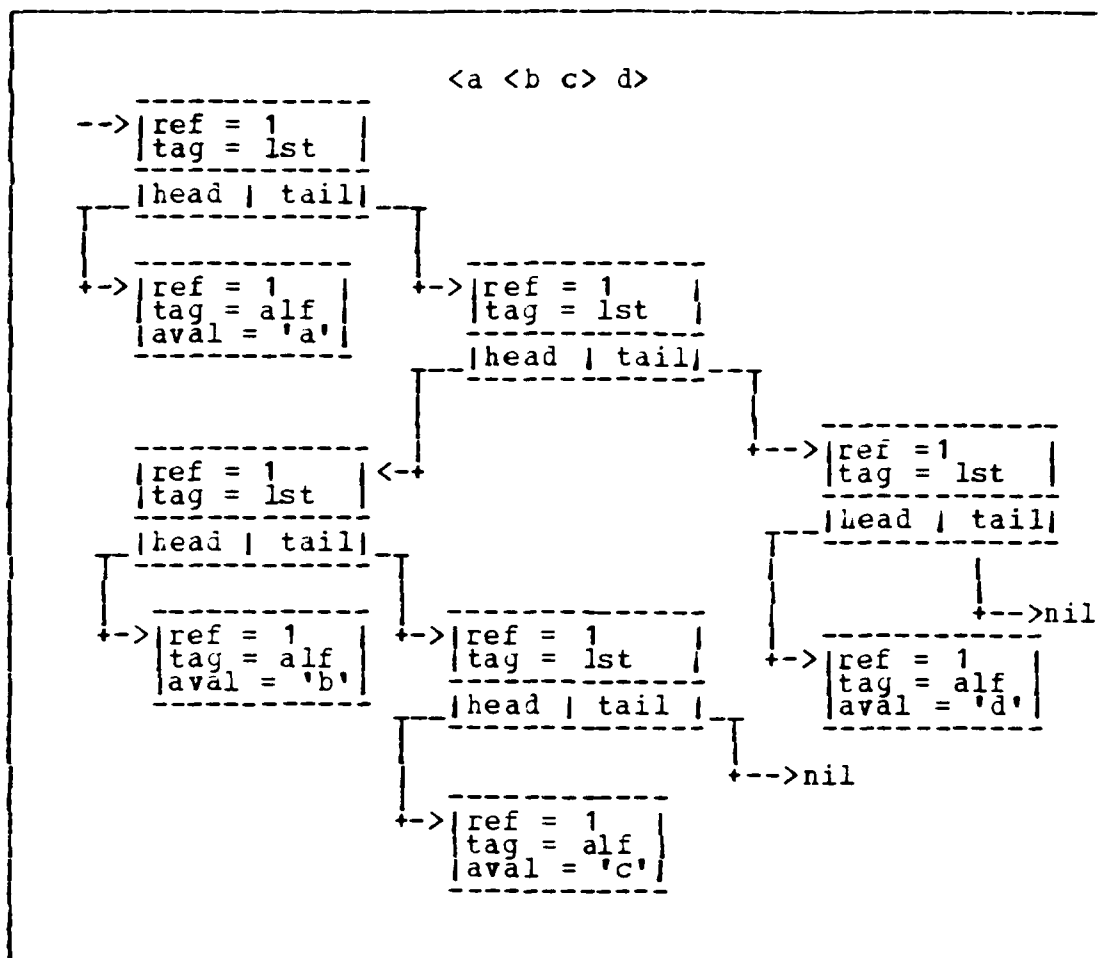


Figure 2.5 List Within a List.

The first list contains three atoms. It is easy to tell that there are three elements in the list by counting the cells that are tagged as lists (lst). The information in the list is contained in other cells that are pointed to by the heads of the list cells. The tails of the list cells point to the next list cell, which in turn points to the next element in the list. The end of the list is represented by the tail field of the last element being set to nil. The example in Figure 2.5 is a list that has as one of its elements another list. Once again if you count the

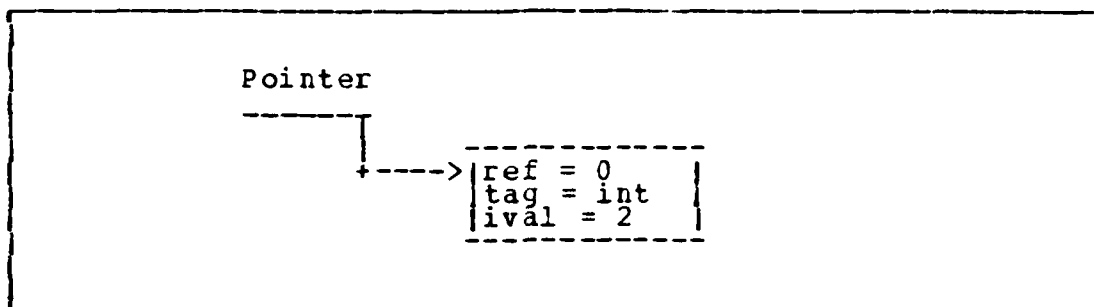


Figure 2.2 Representation of a Cell Containing an Integer.

2. What about lists?

The atoms are the building blocks of ELC and, when placed in sequences form, the lists previously described. Lists are also formed using variant records. Lists are naturally thought of as items that are grouped together because of a common bond. The linked list of Pascal is the natural method to use to represent these groups. This is clear because the interpreter needs to be able to create lists of varying lengths during execution. Since the size of Pascal arrays must be declared before program execution, their use to represent lists is impossible. A language with arrays that could grow dynamically would be more efficient to use in order to avoid the overhead required in maintaining Pascal pointers in linked lists. The list cell is shown in Figure 2.3. The basic cell structure is the same, except that the tag is now 'lst' and the variant portion of the record contains two fields (head and tail) that are pointers to other cells. As mentioned previously, lists are sequences of atoms, lists, or atoms and lists surrounded by angle brackets. In order for the interpreter to recognize where the angle brackets are, the tail field of certain lst cells are set to nil. The representation of two simple lists is shown in Figures 2.4 and 2.5.

refer to the grammar in Appendix A. Lists are sequences of atoms or lists or atoms and lists separated by spaces and surrounded by angle brackets as in Figure 2.1.

```
<list a b c>  
<list a b <list c d> e>  
<letrec append . . .>
```

Figure 2.1 ELC Lists.

Atoms are used to represent information and data in the language, so the interpreter must have a way of representing them. Simple records are not adequate, however, because there are several kinds of atoms and they must be distinguishable. The perfect choice is the variant record, which allows the same record structure to be used for all atoms while permitting some or all of the information to vary depending on the value of a tag field. These variant records are referred to as cells throughout the remainder of the report. Tags for the different atoms are:

- boo (boolean values)
- rea (real values)
- int (integer values)
- alf (identifier; corresponds to Berkeley Pascal alfa type which is a string of ten characters)

Figure 2.2 illustrates the Pascal representation of an atom cell.

Memory management is covered in detail in Section F of this chapter. The other advantage of Pascal is the clarity of the code as opposed to some other languages such as FORTRAN or C. Pascal is not as efficient as these other languages, but in a prototype system like this clarity is a higher priority.

2. Pascal's Disadvantages are Commonly Known

Pascal's disadvantages for this particular implementation are no different than any other; however there are two that deserve special mention. Pascal input-output facilities are very awkward to use. Any type of translating program, whether it be an interpreter or compiler, must scan an input program, either from a file or terminal, before execution. Pascal provides only for input to be read in one character at a time. This technique is obviously very inefficient, especially since it is well known that a good method of improving program efficiency is by reducing the number of I/O calls required. At a minimum, a better language would allow at least an identifier at a time to be read, while the ideal language would allow a large amount of data to be read into a **buffer**, which could then be scanned and used as needed, only more efficiently because it is in main memory. If the interpreter were reading from a disk, a logical amount of data to be read at one time would be an entire track.

C. THE CELL AND THE REPRESENTATION OF ATOMS AND LISTS

1. Atoms

In ELC, as in LISP, there are only two elements, atoms and lists. Atoms are non-divisible entities such as integers, real numbers, characters, and identifiers. For a complete breakdown of atoms and the rest of the language

II. INTERPRETER OPERATIONS

A. ASSUMPTIONS

It is assumed that the reader has a working knowledge of recursion and recursive languages, in particular Pascal. If not refer to Cooper [Ref. 9] for information. The reader must also have knowledge of the Extended Lambda Calculus as presented by MacLennan [Ref. 6]. Complete descriptions of these areas are beyond the scope of this report.

The interpreter is a prototype system, so priorities were given to successful operation and to clarity of code rather than to efficiency. Efficiency was not completely forgotten and suggestions on future improvements in this area are given in Chapter 4, Conclusions.

B. PASCAL IS THE IMPLEMENTATION LANGUAGE

Pascal was chosen as the implementation language for the interpreter for two reasons. First, Pascal is the high level language taught to Computer Science students at the Naval Postgraduate School. Implementation of the interpreter in Pascal will thus facilitate its future use by students without the necessity of learning a new language. Second, using Pascal demonstrates that an interpreter of this type can be written in almost any programming language providing that it has recursion. Pascal, however, is not the ideal language for this type of project.

1. Pascal Does Have Some Advantages

The principal advantage of Pascal is the ability to dynamically allocate memory, which takes the burden of managing an array or heap space away from the programmer.

infinite loops. For examples of such programs see MacLennan [Ref. 6].

Is the halting problem a reason to disregard the value of functional programming? If it is, then all other programming languages should be discarded. It is not unusual for programmers, using conventional languages, to occasionally write programs that go into infinite loops.

Finally, another reason why functional programming languages are not currently popular is that they do not work very efficiently on conventional architectures. As stated previously, most current architectures are von Neumann in nature, meaning they are sequential. The result is that the inherent parallelism of the functional languages cannot be exploited. There is work being done to design new architectures, some specifically for functional languages. One of the most promising is the reduction architecture proposed by Mago, which is described in [Ref. 8].

```

      +: <1, 2>
      FP
      s n [1 2]
      KRC
      <call <var sum> <con 1> <con 2>>
      ELC

```

Figure 1.2 Sum in Three Functional Languages.

are the other implementations more readable because of their conciseness? The point is that readability means different things to different people. It also depends to a certain degree on training. A programmer well versed in FP will undoubtedly feel comfortable with the FP version and might find the ELC notation too verbose and wasteful. On the other hand, a person not familiar with FP or KRC may be able to tell more about what the function is supposed to do by reading the ELC version.

The conclusion is that the readability issue is not a good reason to abandon functional programming. Of course there is a certain amount of learning time required, as with any language, and it may even be more severe in this case due to the mathematical nature of these languages. However, if the benefits of exploiting parallelism and decreasing software maintenance costs can be achieved, they will far outweigh the disadvantage of a longer learning period.

Another problem area that has kept the popularity of functional languages to a minimum is the halting problem as described by MacLennan [Ref. 6]. As stated, since functional programs are constructed from expressions, evaluation order does not matter. This is true, however, only for problems that halt. It is possible to write some functional programs in such an order that will cause them to go into

```
Def! = eg0 --> 1: x dot (.id,! dot sub1.)
```

```
  Note: dot = composition
```

```
  FP
```

```
fact:
  proc(n) recursive returns(fixed);
    dcl (n, v) fixed;
    if n < 2
      then v = 1;
    else v = n * fact(n - 1);
    return(v);
  end fact;
```

```
  PL/I
```

Figure 1.1 Factorial Program in FP and PL/I.

is easier to prove functional programs correct, software maintenance costs could improve dramatically. Early's project also demonstrated this fact in that the assembler written in C took sixty hours to complete compared to twenty for the FP version. One of the main reasons for this fact was that debugging time for the FP version was negligible. This was attributed to the fact that FP programs do what you expect of them since they are so easily proven correct. Functional languages are not without their critics and problems, however, a fact which merits discussion.

There are those that will argue that functional languages should not be used because they are not readable. This varies somewhat depending on the functional language being studied. In Figure 1.2 there are three examples of functions to take the sum of two numbers. They are written in Backus' FP, Turner's KRC, and ELC.

What does "readable" really mean? Is the ELC function more readable because it is obvious that a function is being called (because of the explicit use of the word "call"), or

```

function eval (e, a: list): list;
var T, C, e1p: list;
    e1: alpha;
begin
  if atom(e) then eval := e
  else begin
    e1p := first(e);
    e1 := e1p@, aval;
    if e1 = 'list' then eval := evlis(rest(e), a)
    else if e1 = 'rinsert' then eval := e
    else if e1 = 'con' then eval := first( rest(e) )
    else if e1 = 'var' then eval := assoc( a,
      first( rest(e) ) )
    else if e1 = 'letrec' then eval :=
      letrec( first( rest(e) ),
        first( rest( rest(e) ) ),
        first( rest( rest( rest(e) ) ) ), a )
    else if e1 = 'lambda' then begin
      new(C, alf);
      cellcount(1, 'eval');
      with C@ do begin
        tag := alf;
        aval := 'closure';
      end;
      eval := cons( cons(C, e), cons(a, nil) );
    end {if e1 = 'lambda'}
    else if e1 = 'if' then eval := evcon( rest(e), a )
    else if e1 = 'call' then
      eval := apply( eval( first( rest(e) ), a ),
        evlis( rest( rest(e) ), a ) )
    else if e1 = 'apply' then
      eval := apply( eval( first( rest(e) ), a ),
        eval( first( rest( rest(e) ), a ) ) )
    else if e1 = 'let' then begin
      {First, evaluate actual parameters and then
      form the environment of evaluation for the
      let statement}
      T := pairlis( evlis( first( first( rest(e) ) ), a ),
        evlis( first( rest( first( rest(e) ) ) ), a ), a )
      eval :=
        eval( first( rest( rest( first( rest(e) ) ) ) ), T );
    end
    else errormsg('eval');
  end
end {Function eval};

  '@' Indicates pointer

```

Figure 2.6 Function Eval.

<list a b c>

the rest of the list or <a b c> is returned.

- con 'Con' tells the interpreter that the remainder of the list is a constant, so it is returned as such. Examples are:

```
< <first <prim first>> <rest <prim rest>>. . . >
```

Figure 2.7 Primitives Association List.

```
<con 1> = 1
```

```
<con <1 2 3>> = <1 2 3>
```

- var The keyword var, tells the interpreter to search the current environment of execution for the value of a certain bound variable. For example, if <var x> was sent to eval and the association looked like

```
<<x 5> <y 'Navy'> <z 1400>. . .>
```

eval would return the value of 5 for x. The search of the association list is performed by the assoc function of the interpreter. Refer to the source code for the interpreter found in Appendix C for a more detailed discussion of the assoc function.

```
<lambda <x> <call <var sum> <var x> <var x>>>
```

Figure 2.8 Lambda Expression.

- lambda Lambda expressions are ELC's analog to the procedure of conventional programming languages. These expressions are templates for solving certain problems using variables that must be bound to actual values before evaluation can take place. This template is commonly known as an abstraction. The example given in

2.8 is a lambda expression that can take any x , where x is an integer or real number, and add it to itself. It is currently not executable because no actual value for x is present. Since evaluation cannot be completed until later, the interpreter prepares the lambda expression for future execution by forming a closure. This is accomplished by using the primitive cons to add the keyword 'closure' to the front of the lambda expression and then using cons once again to add this to the front of the current environment, which has been placed in a list by itself. All that is left is to bind x with a value and add that to the current environment for execution to take place. This is accomplished by the apply function, which is triggered by the keyword 'call'.

```

      <call <var sum> <con 2> <con 3>>
      Call to Primitive Function

<call <lambda <x> <call <var sum>
                      <var x>
                      <var x>><con 5>>
      User Defined Function

```

Figure 2.9 Using Call to Invoke Functions.

- call The keyword 'call' evokes the interpreter function apply to evaluate ELC function calls. The two simple examples given in Figure 2.9 are of a direct call to a primitive function and a call of the lambda expression discussed in the last section with the actual value of 5. The execution of each is traced below. Refer to Figure 2.6 to follow the trace.

```
<call <var sum> <con 2> <con 3>>
```

- 'call' is recognized by eval
- <var sum> is sent to eval with the current environment
- 'var' is recognized by eval
- 'sum' is looked up in the current environment by function assoc and <prim sum> is returned.
- The rest of the rest of the expression, which is <<con 2> <con 3>> is sent to function evlis which in turn sends each of the elements of the list to function eval with the current environment. Evlis returns a list of the results. In this case <2 3> is sent to function apply as the actual parameter.
- Function apply takes a function and applies it to a certain number of arguments. It acts somewhat like eval in that it strips off the first element of the list sent to it to determine how to precede. Since the first element is 'prim' the interpreter knows that the following element is the name of a primitive function. The result is that the function name, 'sum', and the arguments are sent to another function applyprim for final evaluation.
- sum, <2 3> are sent to applyprim.
- 2, 3 are sent to function sum.
- A pointer to the answer is sent back eventually reaching the initial call of function eval, the answer is printed, and evaluation stops.

- Note: The recursive nature of the interpreter is now clear, even for such a simple program. This point affects efficiency and should be considered as an area for future improvement.

```
<call <lambda <x> <call <var sum>
                        <var x>
                        <var x>>> <con 5>>
```

- 'call' recognized
- <lambda <x> <call <var sum> <var x> <var x>>> sent to eval with current environment.
- 'lambda' recognized and a closure is formed as follows <<closure lambda <x> <call <var sum> <var x> <var x>>> a > where a is the current environment.
- <con 5> is sent to eval; 5 is returned.
- The closure and 5 are sent to function apply.
- In function apply 'closure' is recognized, so the body of the function call <call <var sum> <var x> <var x>>> is sent to function eval. But an environment must be created before evaluation can be completed.
- x, 5, and the current environment is sent to function pairlis where the new environment is created by forming an attribute value pair of x and 5, <x 5>, and adding this to the current environment.
- Evaluation of the function now proceeds as the first example, except when <var x> is sent to eval the new environment is searched finding the value 5.

The consistency between how primitive and user defined functions are evaluated is now clear. This regularity aids the programmer because only one convention must be remembered to invoke all functions.

```
<if <<call <var equal> <con 0> <con 3>>
      <con 'true'>
      <con 'false'>>>
```

Figure 2.10 EIC Conditional.

- if The keyword 'if' signals that the remainder of the list is a conditional statement, so the rest of the list is sent to function `evcon`, which first determines the value of the first sublist, which must in turn be a call to one of the Boolean functions. In Figure 2.10,

```
<call <var equal> <con 0> <con 3>>
```

is the condition. Function `evcon` sends the conditional to function `eval` with the current environment of evaluation. If the condition is not a Boolean function call an error will occur. If the condition evaluates to true, the result of `evcon` is the evaluation of the next sublist by `eval`. If the condition is false, the result is the evaluation of the last sublist. In the example, since 0 and 3 are not equal the condition is false so the last sublist is sent to `eval`, resulting in the constant 'false' being returned.

- Letrec The keyword 'letrec' is a signal to create a special environment for the evaluation of a recursive function. See Figure 2.11. There are four elements that must be considered:

- function name In this case 'append'

- lambda expression The abstraction
- body of the letrec Call to the function itself or another letrec expression.
- current environment

As with the normal function call a closure is formed and this is added to the front of the current environment. The difference is that the environment part of the closure points back to the point where the closure was inserted in the current environment. This is done so the function can be recursively called if need be or other var parameters can be locked up in the environment. See Figure 2.11 to see how the environment for the append function is constructed. As stated, letrec statements can be nested by including them as the body of another letrec, thus allowing the programmer to call any of the recursive functions above it in the body of the last recursive function. These functions can only look back and not forward. For examples see Appendix B, Sample Programs.

- Let The 'let' statement is simply a sugared version of the lambda statement and is included for clarity. Instead of writing

```
<call <lambda<x> <call <var sum>
                        <var x>
                        <var x>>> <con 5>>>
```

the let statement allows you to write the expression in Figure 2.12. In general, <let <<x...> <y...> >> means let x equal y in expression B. Any number of arguments can be included in the lists beginning with x and y. This type expression is particularly valuable if you want to assign a user defined function (lambda expression) a name which can then be called at any time. Consider the doubling function in Figure 2.12. The doubling function could have been

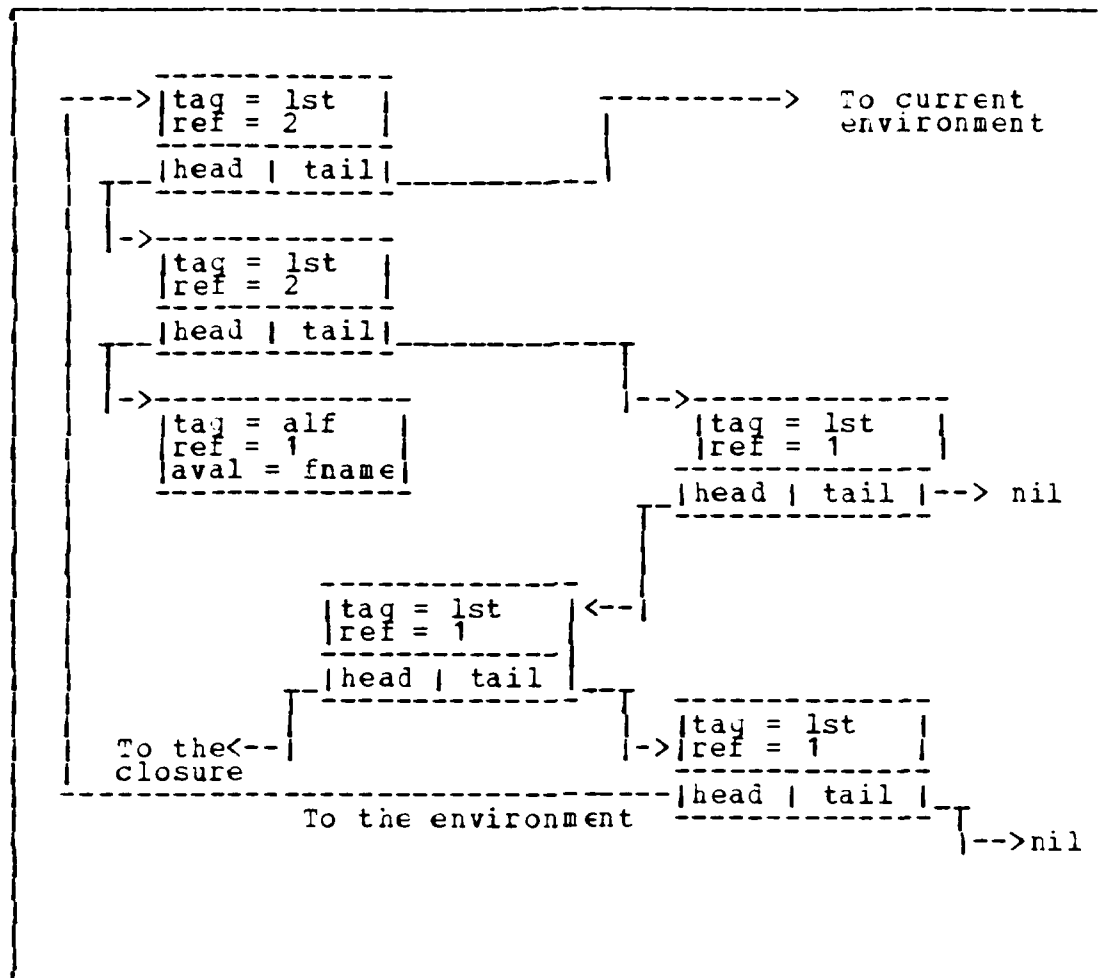


Figure 2.11 Letrec Environment.

accomplished using a single lambda expression as in Figure 2.8, but the `let` statement makes the function call expression

`<call <var double> <con 2>>`

clearer. Once again, expressions can be nested by inserting another `'let'` statement for the B expression or even a `'letrec'` statement. Examples are given in Appendix C, Sample Programs.

```

<let <<double> <lambda <x>
      <call <var sum>
            <var x>
            <var x>>>
      <call <var double>
            <con2>>>>

```

Figure 2.12 Doubling Function.

- apply The keyword 'apply' triggers much the same action as 'call', except the arguments to the function are placed in a separate list as in

```

<apply <var sum> <list <con 2> <con 3>>>

```

The reason this feature is included is that some of the useful ELC programs require that arguments be reversed before functions are applied to them. This can only be accomplished if they are placed in a list so a recursive function call can reverse the elements. There is no primitive function included to handle this situation.

2. Printing Results

After function eval has completed evaluation, the result is in a tree form exactly like that described for the program itself. A pointer to the top of this tree is passed to procedure printval, which simply walks the tree and prints the information found in the leaves. This is done by checking the tags of the cells. If a cell's tag is 'lst', there is no information in the cell, only head and tail pointers. Since it is a list a left bracket must be printed. At that point the left and right cells are sent to printval recursively until a cell other than a 'lst' cell is found. These cells are obviously leaves of the tree so the variant portion of the cell is printed. This continues

until a tail pointer of one of the 'lst' cells is nil. This signals the end of the list so a right bracket is printed and evaluation is completed.

F. MEMORY MANAGEMENT

1. Overview

Throughout the execution of a program many of the cells that are created become useless because they can no longer be accessed. Good examples of this are any of the binary functions included in the interpreter as primitives. For example, consider the sum function, Figure 2.13. Notice that two pointers are delivered to the sum function which point to the cells that contain the numbers to be added. After these numbers are added, the results are placed in another cell. The two cells that held the intermediate results are no longer needed and should be returned to a free list to be used again later. Another example is the creation of new environments for lambda expressions before they are evaluated. After the evaluation of the lambda expression, the cells that made up the attribute value pair that was added to the current environment are no longer needed and should be returned.

Since this is a prototype system, reference counting was chosen as the memory management method because of its simplicity and ease of installation. The model followed is outlined by MacLennan in [Ref. 6]. Reference counts refer to the number of pointers that a particular cell has referencing it at any one time. This count is kept in an additional field in each cell. Refer to Figure 2.4 to see the reference counts for a simple list. Reference counts must be incremented if additional references to cells are made. Reference counts in cells must be decremented if references are destroyed. References can be destroyed by overwriting

```

function sum(x, y: list): list;
var R, I: list;
begin
  if (x@.tag=int) and (y@.tag=int) then begin
    if empty then begin
      new(I, int);
      cellcount(1, 'sum');
    end
    else
      I := freecell;
      with I@ do begin
        ref := 0;
        tag := int;
        I@.ival := x@.ival + y@.ival;
      end;
      sum := I;
    end
  else if (x@.tag=rea) and (y@.tag=rea) then begin
    if empty then begin
      new(R, rea);
      cellcount(1, 'sum');
    end
    else
      R := freecell;
      with R@ do begin
        ref := 0;
        tag := rea;
        R@.rval := x@.rval + y@.rval;
      end;
      sum := R;
    end
  else
    errormsg('sum') {Type mismatch}
  end; {Function sum}

```

'@' Indicates Pointer

Figure 2.13 Function Sum.

pointers with other pointers by using an assignment statement or if the cell containing the pointer itself becomes inaccessible. Whenever a cell's reference count becomes zero it can be returned to the system because it is no longer accessible by the program.

The interpreter manages reference counts through the use of four procedures:

- ptrassn Overwrites pointers
- decr Decrements cell reference counts

- return Returns cells to the free list
- freecell Retrieves cells from the freelist

Figure 2.14 shows how function ptrassn works.

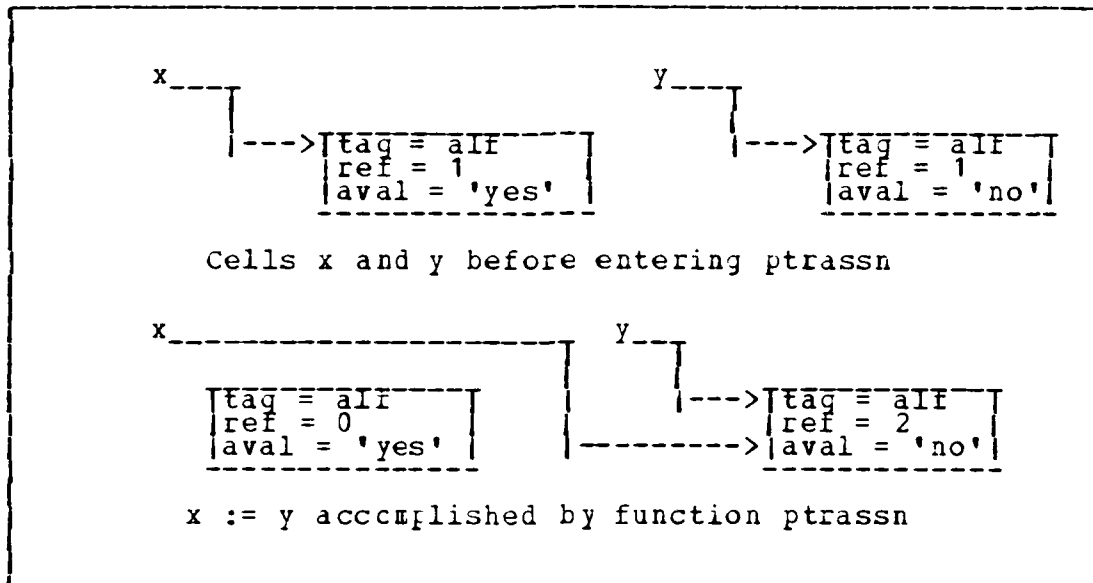


Figure 2.14 Function Ptrassn.

First, the reference count of the cell that x points to is decremented. Next the reference count of y is incremented. Finally x is assigned the value of y. It is important that the assignment statement be done last so the reference count of x can be decremented. If not done x would no longer point to the correct cell and the reference count of y would actually be decremented.

Procedure `decr` is used to decrement the reference counts of all cells. If a reference count of a cell goes to zero, `decr` is recursively called over the entire list until all cells with references of zero are found and returned to a freelist maintained by procedure `return`.

Procedure return links all the free cells together by first making them all '1st' cells and linking them through the tail fields with the tail field of the last cell in the list being set to nil.

Freecell is a procedure that is used to recover cells from the freelist instead of creating newcells by using the Pascal new facility. Each location in the interpreter that needs to create new cells first checks to see if the freelist is empty. If it is not, a cell is taken from the freelist instead of creating a new one. Actually a freelist is not necessary. Cells could be returned to the system using Pascal's dispose feature. Since this is a prototype system, the freelist is maintained to make it easier to maintain statistics on the number of cells being returned.

2. Conventions

a. Cell Creation

The reference counts of cells are set to zero when they are created. This must be done so that when a program is read into the interpreter reference counts in all cells are set to one. To understand this, study the cons function which is used to build up the program list when it is initially read. Cons uses the ptrassn procedure to set the head and tail of the connecting cells. If a cell is created during readin and its reference count is set to one, that reference count will go to two when that cell is sent to cons. The result is a reference count that is greater than it should be. If, however, the cell is created with a reference count of zero, it will be set to one when it is sent to cons, which in turn sets the head and tail of the connecting cell with the ptrassn procedure. The only special case that must be recognized is the cell at the very

top of the program tree which must be physically set to one after readin since it is never sent to the ptrassn procedure.

b. Local Declarations

If locally declared pointer variables are used to overwrite other pointers their reference counts must be decremented before the procedure they are declared in is completed. This is done because locally declared variables are only visible within the procedures they are declared in and then destroyed. If the reference counts they generated are not decremented, excess reference counts to some cells are the result.

c. Passed Parameters

The reference counts of cells referenced by pointer variables passed to procedures or functions by value must be incremented upon entering the procedure and decremented when leaving the procedure. It is easy to see how cells can be recovered in this manner. If the reference count of a cell is zero when it enters a procedure it will be incremented to one during the execution of the procedure and then decremented to zero and reclaimed when the procedure is finished.

Function Reverse

Purpose

Takes any list as an argument, reverses the elements of the list and places them in another list.

Practical Application

Reverse is used primarily as a sub-function for larger programs. It is the nature of recursion that many times result lists are constructed in reverse order. The reverse function is then needed to regain the proper order.

Discussion

There are two versions of reverse included, reverse and revaux. Reverse makes use of the primitive 'conr' to build the result list where revaux utilizes a null list, (<>), to build the result list using a series of calls to 'cons'. It is interesting to study the differences in efficiency between the two functions. Reverse is faster and uses less memory. The reason is because the primitive conr was included in the interpreter, which shortens the number of steps required. Whether time and memory savings justify including another primitive in the interpreter depend on how often it is used. The use of the reverse function is minimal and would not justify including a primitive only for its use.

Source Code

```
<letrec reverse
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var conr>
        <call <var reverse>
          <call <var rest> <var L>>>
        <call <var sub> <var L> <con 1>>>>>>
```

702	83	readval
704	108	nonblank
714	25	readlist
770	1	readint
827	199	digit
835	257	letter
843	57	readident
867	83	readval
879	11	evcon
880	157	evlis
881	52	apply
882	1	letrec
884	190	eval
947	1	letrec
1012	11	evcon
1041	157	evlis
1093	41	applyprim
1198	52	apply
1239	28	dcprim
1261	1	readfname

Statistics

System time was 366 milliseconds
User time was 6600 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	402	
readiden	57	
readint	1	
letrec	6	
null	11	

Total cells 561

Profile for append function

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 09:05 1984

Line	Count	
1	1	func
33	21	printval
36	505	cellcount
63	1477	nullp
84	3123	first
94	1692	rest
122	402	cons
258	10	sub
539	190	atomp
547	1477	nullp
564	11	null
599	94	assoc
643	33	pairlis
663	21	printval

```

<call <var append>
  <list <con g><con h> <con j>>
  <list <con g> <con r><con s>>>>!
```

Results of Append Function (Compiled Interpreter)

Enter Expression

<a, b, c, d, e, f, g, h, i, j, j, l, m, n, o, p, q, r, s, t>

Evaluation Completed

Statistics

```

System time was      183 milliseconds
User time was        616 milliseconds
```

```

-----
|Module           Cells created |
|-----|
|dcprim           84           |
|cons             402          |
|readiden         57           |
|readint           1           |
|letrec            6           |
|null             11           |
|-----|
Total cells        561
```

Results of Append (EIC Interpreter interpreted by Berkeley Pascal)

Enter Expression

<a, b, c, d, e, f, g, h, i, j, j, l, m, n, o, p, q, r, s, t>

Evaluation Completed

APPENDIX B

SAMPLE PROGRAMS

General

The statistics in this appendix are referred to as compiled versus interpreted. This means compiled and interpreted versions of the ELC interpreter. Also all statistics refer to programs run on an interpreter without a memory manager. Run times are much slower when the memory management system is used.

Function Append

Purpose

The append function concatenates lists. This is different than the primitive cons which makes its first argument the first element of another list.

Practical Application

Append could be useful if the argument lists were large databases that had to be combined. This is common practice in database work where many small databases are combined to form a whole.

Source Code

```
<letrec append
  <lambda <L M>
    <if <<call <var null> <var L>>
      <var M>
      <call <var cons>
        <call <var sub><var L><con 1>>
        <call <var append>
          <call <var rest><var L>>
          <var M>> >>>>
```

```

<conditional> ::= '< if <boolean exp.>
                    <list> | <lookup var> | <const exp.> |
                    <prim applic.> | <boolean exp.>
                    <list> | <lookup var> | <const exp.> |
                    <prim applic.> | <boolean exp.>'

<boolean exp.> ::= '< call <var> <boolean prim> '>'

<boolean prim> ::= atom | null | equal | memb | GT | LT | GE | LE

<prim call> ::= '< var> <primname> '>'

<primname> ::= first | rest | cons | atcm | null | sum | subt | prod | divi | sub |
              equal | len | memb | repr | GT | LT | LE | GE

<prim applic.> ::= '< call '<prim call> <list> ee1 |
                  <lookup var> ee1 | <const exp.> ee1 '>'

<list> ::= '< list' <letter> ee1 | <letter> ee1 <list> ee1 |
           <number> ee1 <number> ee1
           <list> ee1 <letter> ee1
           <number> ee1 '>'

<lookup var> ::= '< var> <letter> | <identifier> '>'

<const exp.> ::= '< con> <number> ee1 | <list> | <letter> '>'

<actuals> ::= <list> | <lookup var> | <const exp.> |
              <lookup var> <lookup var>
              <list> ee1 <list> ee1
              <const. exp.> <const. exp.>

<letter> ::= <a..z | A..Z>

<number> ::= <digit> ee1 | <digit> ee1 '.' <digit> ee1

<digit> ::= <0..9>

<atom> ::= letter | number | identifier

```

APPENDIX A
ELC GRAMMAR

Note: ' ' denotes literal ccopy.

ee denotes superscript. (ee1 means one or more)

```
<ELC program> ::= atom|list|<recursive exp.>|<abstraction>|
                  <application>|<let> '!'

<recursive exp.> ::= '< letrec' <rec identifier>
                  <lambda exp.> <body> '>'

<body> ::= '<call ' <rec identifier> <actuals>|
          <recursive exp.>|<let> '>'

<rec identifier> ::= <identifier>

<identifier> ::= <letter> ee10|<<letter><number|letter>>ee10
  Note: Ten or less letters. Corresponds to the Berkeley
  Pascal built in string, packed array 1..10 of char.

<abstraction> ::= '< lambda' <bound variables>
                  <abstraction body> '>'

<let> ::= '<let<'<bound variables> '<'
          <abstraction>|<application>|
          <primitive application >|
          <conditional>|<recursive exp.> '>'

<application> ::= '<' <lambda exp.> <actuals>ee1 '>'

<bound variables> ::= <letter> ee1| <identifier> ee1

<abstraction body>::='<'<conditional>|<prim call>|
                  <abstraction>'>'
```

data must be inserted in the program itself. This could be done easily by modifying the interpreter to recognize key words that trigger a read operation.

Finally, the interpreter should be written in a more portable version of Pascal. Berkeley Pascal has several non standard features such as the alfa type that make its code machine dependent.

D. LESSONS LEARNED

Writing programs in ELC becomes easier with experience. This was primarily because detailed programs are built by combining several smaller programs. For example, the program that generates the trig table is made of six functions, each a program in its own right. Once the single function programs are tested, they can be easily and reliably used to build other programs.

ELC programs also force the user to think about problems as a whole when programming. For example, when writing the append function one asks the question, "How would I physically solve this problem?". The answer is by taking one element at a time from one list and adding that element to the second list until the first list is empty. That explanation is exactly how to solve the problem recursively and the ELC program reflects that. If a conventional language was used to solve the problem, however, the programmer would have to be concerned with many low level constructs such as assignment statements and counter variables. After some experience, dealing with problems at a higher level became very comfortable, particularly because many of the problems encountered were solved using the same technique.

B. STRUCTURING PROGRAMS

Programs are contained in one list so they can be written in one line, but this does not always present a clear view of what the program does. A natural method of structuring ELC programs evolved through experience. The method is to stack the arguments of functions under their calls. For example, consider this call to the primitive function `cons`.

```
<call <var cons>
      <list a b>
      <list c d e>>
```

This convention becomes very useful in large programs when many functions must be nested. The conditional can be structured as

```
<if <<call <boolean exp.>
      <True consequent>
      <False consequent>>>
```

Once again the arguments are stacked for clarity.

C. FUTURE IMPROVEMENTS

There are several improvements that can immediately be accomplished for the interpreter.

The code could be made more English like. This could be done by writing a front end to translate a higher level code into the ELC code used in this report or by completely changing the ELC grammar. While making more readable programs this feature would decrease efficiency.

In the opposite direction the code could be made more mathematical in nature, similar to the notation used by Backus in FP. The tradeoff in that case would be efficiency versus readability.

A feature should also be added to allow data for the ELC programs to be read from the terminal or a file. Currently

these values and subscript them based on the number of scoping lines crossed in getting from a use of the variable to its definition. A detailed explanation of this method is given by MacLennan [Ref. 6]. The beauty of this method is that it eliminates the overhead of managing the pointers of the association list and the need to recursively search it, both very expensive operations in terms of efficiency.

Comparisons are also made in Appendix B between two recursive ELC programs and their Pascal counterparts. The programs calculate n factorial and generate the first n elements of the Fibonacci sequence. The Pascal programs run faster, which is not surprising because there is one less layer of software involved in their execution. The time differences are less than a second, however, and with minimal improvements to the interpreter can be improved.

Finally, a more efficient memory managing system should be implemented. Programs executed with the memory manager are very slow as can be seen by comparing the run times of the programs listed on the last page of Appendix B with their execution times without the memory manager. A mark and sweep system would be more efficient because the execution of a program would not be impeded unless all the allocated memory was used. On the other hand, the reference counting system invokes memory management procedures and functions throughout program execution. Since most programs will not use all allocated memory they would run at near normal speed (normal speed being the time to execute a program without the memory manager). The tradeoff is that the interpreter will have to allocate its own heap space and manage it.

IV. CONCLUSIONS

A. EFFICIENCY

Appendix B contains statistical data for several ELC programs. Times for program execution are given for both interpreted and compiled versions of the interpreter. It is not suprising that the compiled version always ran much faster and is recommended for use. The interpreted version of the ELC interpreter was used throughout development, however, because it took half the time that compiling required.

Profiles for all sample programs are also included in Appendix C. These profiles reveal hints on how the interpreter could be more efficient. The data shows that the interpreter spends most of its time in the primitive functions, such as null, first, sum, etc.. Efficiency could be improved by writing these functions in a lower level language, such as assembly language, and then linking these modules in at run time. This would not be difficult because these functions are very short and they are all constructed in the same manner, e.g., all the Boolean functions are the same except for the condition being checked. When the lower level code is completed for one of the modules it could be used as a template for the others.

Efficiency can also be improved by replacing the association list mechanism for looking up the value of variables. Since the pairlis function always adds new attribute value pairs to the front of the current environment before evaluation, it is clear that searching an association list is not always necessary because we know the value is at the front of the list. A better method is to use an array to hold

C. ERROR MESSAGES

The best way to become familiar with the interpreter's error messages is to study the error handling procedure of the interpreter itself, Appendix C. The procedure is set up like a table displaying all the error messages and they can be easily traced back to their sources. The interpreter is designed to halt execution immediately upon detection of an error.

At this point programs can be typed directly from the terminal and executed. To stop execution follow the last program with a '!'. A statistical summary is given showing the number of cells created, number of cells returned to the system, and time of execution before termination. Evaluation is successfully completed with the message

Evaluation Completed.

If a long program is to be executed, it is recommended to place it in a file so editing can be accomplished, if necessary. The command to interpret a program from a file is

obj

The interpreter then responds with a prompt to ask for the name of the file where the program exists.

File for ELC Program:

The filename can be up to eighty characters in length.

B. EXECUTION TRACE

After the method of loading the program is determined, the user is questioned if a trace is desired. A trace prints out pertinent intermediate results as the program is executed to help in debugging. Two examples of items printed out are: each expression sent to function eval and results of looking up a var parameter in an association list. Not all expressions can be printed out because some structures are recursive and an attempt to print them out results in an infinite loop. To avoid infinite loops additional questions are asked about the user's desire to print out certain structures when there is a possibility that they could be recursive. Invoking the trace facility obviously slows execution a great deal but can be quite helpful in debugging a program.

III. HUMAN INTERFACE WITH THE INTERPRETER

A. LOADING A PROGRAM

The interpreter is activated by first compiling or interpreting it using the facilities of Berkeley Pascal under Unix 4.2 BSD as shown in the following example:

Interpreted Code

'pi' <filename of the interpreter>'.p'

Compiled Code

'pc' <filename of the interpreter>'.p'

If interpreted, an executable file named 'obj' is created; if compiled, an executable file, 'a.out' is created. The compiled version runs much faster as seen by the time of execution statistics located in Appendix B, Sample Programs. It is recommended that the names of these files be changed to something more intuitive, such as 'ELC' or 'Interp', etc..

The interpreter can be run in interactive mode or a program can be executed from another file. Interactive mode should only be used for short programs or if the interpreter is being used as a calculator to perform basic mathematical computations. The big drawback to interactive use is that no editing can be done on programs that are longer than one line when typing at the terminal. If interactive mode is desired, the following command should be issued. Interpreted code is assumed in all examples.

obj i

The 'i' toggle tells the interpreter that interactive mode is desired. A logon message with date and time appears next, followed by the prompt:

Enter Expression

<call <var reverse> <list a b c d e f g h i j>>>>!

Results of reversing a ten element list (Compiled version)

Enter Expression

<j, i, h, g, f, e, d, c, b, a>

Evaluation Completed

Statistics

System time was 100 milliseconds

User time was 516 milliseconds

Module	Cells created
ldcprim	84
icons	323
readiden	42
readint	1
letrec	6
null	11
conr	9

Total cells 476

Reversing a ten element list(interpreted)

Enter Expression

<j, i, h, g, f, e, d, c, b, a>

Evaluation Completed

Statistics

System time was 316 milliseconds

User time was 5716 milliseconds

Module	Cells created
dcprim	84
cons	323
readiden	42
readint	1
letrec	6
null	11
conr	9

Total cells 476

Profile of reverse function

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 09:08 1984

Line	Count	
1	1	func
33	11	printval
36	420	cellcount
63	1349	nullp
84	2861	first
94	1545	rest
122	323	cons
137	10	conr
258	10	sub
539	169	atomp
547	1349	nullp
564	11	null
599	83	assoc
643	22	pairlis
663	11	printval
702	67	readval

704	91	nonblank
714	24	readlist
770	1	readint
827	167	digit
835	210	letter
843	42	readident
867	67	readval
879	11	evcon
880	135	evlis
881	52	apply
882	1	letrec
884	169	eval
947	1	letrec
1012	11	evcon
1041	135	evlis
1093	41	applyprim
1198	52	apply
1239	28	dcprim
1261	1	readfname

Function Revaux

Source Code

```
<letrec revaux
  <lambda <L M>
    <if <<call <var null> <var L>>
      <var M>
      <call <var revaux>
        <call <var rest> <var L>>
        <call <var cons>
          <call <var sub> <var L> <con 1>>
          <var M>
        >>>>
      <call <var revaux>
        <list a b c d e f g h i j>
        <con <>> >>!
```

Results of Revaux (10 element list, compiled)

Enter Expression

<j, i, h, g, f, e, d, c, b, a>

Evaluation Completed

Statistics

System time was	166 milliseconds
User time was	566 milliseconds

Module	Cells created
dcprim	84
cons	383
readiden	47
readint	1
letrec	6

|null 11 |

Total cells 532

Results of revaux (interpreted).

Enter Expression

<j, i, h, g, f, e, d, c, b, a>

Evaluation Completed

Statistics

System time was 366 milliseconds

User time was 6333 milliseconds

|Module Cells created |

|-----|

|dcprim 84 |

|cons 383 |

|readiden 47 |

|readint 1 |

|letrec 6 |

|null 11 |

Total cells 532

Profile of Revaux

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.;

Profiled Fri Dec 14 22:46 1984

Line Count

1 1 func

33 11 printval

36 476 cellcount

63	1466	nullp
84	3104	first
94	1672	rest
122	383	cons
258	10	sub
539	180	atomp
547	1466	nullp
564	11	null
599	94	assoc
643	33	pairlis
702	74	readval
704	100	nonblank
714	26	readlist
770	1	readint
827	178	digit
835	226	letter
843	47	readident
867	74	readval
879	11	evcon
880	146	evlis
881	52	apply
882	1	letrec
884	180	eval
947	1	letrec
1012	11	evcon
1041	146	evlis
1093	41	applyprim
1198	52	apply
1239	28	dcprim
1261	1	readfname

Map Functional

Purpose

Functionals are functions that return other functions as results. The map functional allows the user to take any unary function and apply it to the elements of a list, returning a list of the results. In this example, the sine function is mapped across a list of ten angles.

Practical Application

Map could be used extensively in business applications. An example would be an employee database where the same operations must be accomplished on many different records. If salaries were increased across the board, a version of map could be used to achieve this.

Source Code

```
<letrec map
  <lambda <f>
    <lambda <L>
      <if <<call <var null> <var L>>
        <con <>>
        <call <var cons>
          <call <var f> <call <var first><var L>>>
          <call <call <var map> <var f>>
            <call <var rest> <var L>>>>>>>>
        <call <call <var map> <var sin>>
          <list <con 45> <con 60> <con 90>>> >>!
```

Results of map functional (map sine) Compiled

Enter Expression

```
<0.707107, 0.866025, 1.000000, 0.913545, 0.573576,
  0.342020, 0.422618, 0.275637, 0.939693, 0.999391>
```

Evaluation Completed

Statistics

System time was 216 milliseconds
User time was 683 milliseconds

Module	Cells created	
dcprim	84	
cons	445	
readiden	52	
readint	10	
letrec	6	
eval	11	
null	11	
sinp	10	

Total cells 629

Map sine (interpreted)

Enter Expression

<0.707107, 0.866025, 1.000000, 0.913545, 0.573576,
0.342020, 0.422618, 0.275637, 0.939693, 0.999391>

Evaluation Completed

Statistics

System time was 416 milliseconds
User time was 7666 milliseconds

Module	Cells created	
dcprim	84	
cons	445	
readiden	52	
readint	10	

letrec	6	
eval	11	
null	11	
sinp	10	

Total cells	629
-------------	-----

Profile for map functional

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 10:15 1984

Line	Count	
1	1	func
33	11	printval
36	573	cellcount
63	1666	nullp
84	3579	first
94	1959	rest
122	445	cons
411	10	sinp
539	212	atomp
547	1666	nullp
564	11	null
599	104	assoc
643	44	pairlis
663	11	printval
702	103	readval
704	144	nonblank
714	41	readlist
770	10	readint
827	217	digit
835	279	letter
843	52	readident

367	103	readval
879	11	evcon
880	167	evlis
881	73	apply
882	1	letrec
884	212	eval
947	1	letrec
1012	11	evcon
1041	167	evlis
1093	51	applyprim
1198	73	apply
1239	28	dcprim
1261	1	readfname

Halving Function

Purpose

The halving function takes a list of numbers and returns a list of all the elements divided in half. There is really no practical application for this function but it demonstrates the use of the 'bu' functional which changes a binary operator to a unary operator. If you divide a list of integers by 2 it is more efficient to fix the second operand of the division instead of evaluating 2 as a constant each time the division takes place.

```
<letrec map
  <lambda <f>
    <lambda <L>
      <if <<call <var null> <var L>>
        <con <>>
        <call <var cons>
          <call <var f> <call <var first><var L>>>
          <call <call <var map> <var f>>
          <call <var rest> <var L>>>>>>>>
      <let <<bu> <<lambda <f k>
        <lambda <x>
          <call <var f> <var k> <var x>>>> >
      <let <<revf> <<lambda <f>
        <lambda <x y>
          <call <var f> <var y> <var x>>>>>
      <call
        <call <var map>
          <call <var bu>
            <call <var revf> <var divi>>
            <con 2>>>
      <list <con 4> <con 6> <con 8> <con 13>>
      >>>>>>!
```

Results of halving function(compiled)

Enter Expression

< 2, 3, 4, 9, 10, 11, 12,
13, 14, 15>

Evaluation Completed

Statistics

System time was 183 milliseconds

User time was 966 milliseconds

```
-----  
| Module      Cells created |  
|-----  
| dcprim      84             |  
| cons        674            |  
| readiden    87             |  
| readint     11             |  
| letrec      6              |  
| eval        15             |  
| null        11             |  
| divi        10             |  
|-----
```

Total cells 898

Results of halving (interpreted)

Enter Expression

< 2, 3, 4, 9, 10, 11, 12,
13, 14, 15>

Evaluation Completed

Statistics

System time was 483 milliseconds

User time was 10183 milliseconds

```
-----  
|Module          Cells created |  
|-----  
|dcprim          84           |  
|cons            674          |  
|readiden        87           |  
|readint         11           |  
|letrec          6            |  
|eval            15           |  
|null            11           |  
|divi            10           |  
|-----  
Total cells      898
```

Profile for halving function (use of bu).

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 10:03 1984

Line	Count	
1	1	func
33	11	printval
36	842	cellcount
63	2057	nullp
84	4420	first
94	2494	rest
122	674	cons
233	10	divi
539	305	atomp
547	2057	nullp
564	11	null
599	166	assoc

643	103	pairlis
663	11	printval
702	168	readval
704	238	nonblank
714	70	readlist
770	11	readint
827	350	digit
835	448	letter
843	87	readident
867	168	readval
879	11	evcon
880	240	evlis
881	95	apply
882	1	letrec
884	305	eval
947	1	letrec
1012	11	evcon
1041	240	evlis
1093	51	applyprim
1198	95	apply
1239	28	dcprim
1261	1	readfname

equal	1806	
sum	255	
len	411	

Total cells	57682
-------------	-------

Profile for frequency table function.

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 10:20 1984

Line	Count	func
1	1	
33	19	printval
36	57626	cellcount
62	1806	equal
63	664983	nullp
84	1404922	first
94	743026	rest
122	49559	cons
158	255	sum
273	2267	equalp
291	1806	equal
539	70799	atomp
547	664983	nullp
564	4554	null
576	1233	lenp
587	411	len
599	36403	assoc
643	10367	pairlis
665	19	printval
702	530	readval
704	744	nonblank
714	214	readlist

null	4554	
memb	666	
equal	1806	
sum	255	
len	411	

Total cells	57682
-------------	-------

Results of frequency table generator(interpreted)

Enter Expression

```
<<text,      1>
, <of,      1>
, <block,    1>
, <the,      1>
, <is,      1>
, <This,    1>
>
```

Evaluation Completed

Statistics

System time was	23900 milliseconds
User time was	1990866 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	49559	
readiden	313	
readint	3	
letrec	30	
eval	1	
null	4554	
memb	666	


```

    <if <<call <var equal>
        <var k>
        <call <var first>
            <call <var first> <var T>>>>
    <call <var first>
        <call <var rest>
            <call <var first> <var T>>>>
    <call <var lookup>
        <call <var rest> <var T>>
        <var k>>
        >>>>
<let <<occur> <<lambda <w F>
    <if <<call <var equal>
        <call <var memb>
            <var w>
            <call <var dom>
                <var F>>>
        <con true>>
    <call <var lookup>
        <var F>
        <var w>>
    <con 0>>>>>
<letrec freq
    <lambda <T>
        <if <<call <var null> <var T>>
            <con <>>
        <call <var overlay>
            <call <var freq>
                <call <var rest> <var T>>>
            <call <var cons>
                <call <var first> <var T>>
                <call <var cons>
                    <call <var sum>
                        <call <var occur>
                            <call <var first>

```

```

                                <var T>>>
                                <call <var rest>
                                <call <var dom>
                                <var T>>>>
                                <con true>>
                                <con false>
                                <call <var isfinfunc>
                                <call <var rest>
                                <var T>>>>>
                                <con false>>>>>
<letrec overlay
  <lambda <T pr>
    <if <<call <var equal>
      <call <var isfinfunc> <var T>>
      <con true>>
    <if <<call <var null> <var T>>
      <call <var cons> <var pr> <con <>>>
      <if <<call <var equal>
        <call <var first> <var pr>>
        <call <var first>
          <call <var first>
            <var T>>>>
        <call <var overlay>
          <call <var rest> <var T>>
          <var pr>>>
        <call <var cons>
          <call <var first> <var T>>
          <call <var overlay>
            <call <var rest> <var T>>
            <var pr>>>>>>
      <con Tnotffunc>>>>
    <con <>>>
  <lambda <T k>
    <if <<call <var null> <var T>>
      <con notfound>

```

Frequency Table Generator

Purpose

This program takes a finite set of text and creates a frequency table of the words used and how many times they are used.

Practical Application

This program could be useful if extended to recognize patterns in large blocks of data. Also, in military intelligence work, it could be valuable to see how many times a persons name appears in a newspaper to gain some insight into how important they might be.

```
<letrec dom
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var cons>
        <call <var first>
          <call <var first> <var L>>>
        <call <var dom>
          <call <var rest>
            <var L>>>>>>>

<letrec isfinfunc
  <lambda <T>
    <if <<call <var null> <var T>>
      <con true>
      <if <<call <var equal>
        <call <var len>
          <call <var first> <var T>>>
        <con 2>>
      <if <<call <var equal>
        <call <var mem>
          <call <var first>
            <call <var dom>
```

94	1148	rest
122	395	cons
137	3	conr
258	3	sub
411	3	sinp
539	123	atomp
547	988	nullp
564	8	null
599	61	assoc
643	23	pairlis
663	4	printval
702	154	readval
704	219	nonblank
714	65	readlist
770	4	readint
827	377	digit
835	466	letter
843	85	readident
867	154	readval
879	8	evcon
880	96	evlis
881	39	apply
882	2	letrec
884	123	eval
947	2	letrec
1012	8	evcon
1041	96	evlis
1093	29	applyprim
1198	39	apply
1239	28	dcprim
1261	1	readfname

Results of composition (interpreted)

Enter Expression

<1.000000, 0.866025, 0.707107>

Evaluation Completed

Statistics

System time was 583 milliseconds

User time was 5966 milliseconds

```
-----  
|Module      Cells created |  
|-----  
|dcprim      84           |  
|cons        395          |  
|readiden    85           |  
|readint     4            |  
|letrec      12           |  
|eval        2            |  
|null        8            |  
|conr        2            |  
|sing        3            |  
|-----
```

Total cells 595

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Mon Dec 17 18:51 1984

Line	Count	
1	1	func
33	4	printval
36	539	cellicount
63	988	nullp
84	2111	first

```

                                <call <var rest >
                                <var L >>> >>>>

<let <<dot> <<lambda <f1 f2>
      <lambda <x>
      <call <var f1><call<var f2><var x>>>>>>
<call
      <call <var dot> <var mapsin> <var reverse>>
<list <con 45> <con 60> <con 90>> >>>>>!
```

Results of composition (compiled)

Enter Expression

<1.000000, 0.866025, 0.707107>

Evaluation Completed

Statistics

System time was 250 milliseconds

User time was 616 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	395	
readilen	85	
readint	4	
letrec	12	
eval	2	
null	8	
conr	2	
sinp	3	

Total cells 595

Composition Functional

Purpose

Composition allows the output of one function to act as the input to another function.

Practical Application

Composition could be used in business applications as a way of querying a database with multiple conditions. For example, utilizing the filter function, a user could ask for records of employees that satisfy a certain condition and then apply another call to filter with a further refined condition such as all employees in department 5 that make more than two thousand dollars a week. In this example `mapsin` and `reverse` are composed. The composition function is named `dot` to correspond to Backus's FP language which actually includes this as an operator in the language.

Source Code

```
<letrec reverse
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var cons>
        <call <var reverse>
          <call <var rest> <var L>>>
        <call <var sub> <var L> <con 1>> >>>>

<letrec mapsin
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var cons>
        <call <var sin>
          <call <var first> <var L>>>
        <call <var mapsin>
```

663	12	printval
702	150	readval
704	205	no:blank
714	55	readlist
770	15	readint
827	332	digit
835	427	letter
843	80	readident
867	150	readval
879	32	evcon
880	260	evlis
881	93	apply
882	1	letrec
884	335	eval
947	1	letrec
1012	32	evcon
1041	260	evlis
1093	82	applyprim
1198	93	apply
1239	28	dcprim
1261	1	readfname

Module	Cells created	
dcprim	84	
cons	531	
readiden	80	
readint	15	
letrec	6	
null	22	
LE	10	

Total cells 748

Profile for collate function

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 10:07 1984

Line	Count	
1	1	func
33	12	printval
36	692	cellcount
63	2566	nullp
84	5526	first
94	2921	rest
122	531	cons
258	30	sub
384	10	LEp
394	10	LE
539	335	atomp
547	2566	nullp
564	22	null
599	166	assoc
643	33	pairlis

< 2, 3, 3, 5, 6, 6, 7,
8, 9, 10, 12>

Evaluation Completed

Statistics

System time was 166 milliseconds
User time was 1066 milliseconds

```
-----  
| Module           Cells created |  
|-----|  
| dcprim           84             |  
| cons             531            |  
| readiden         80             |  
| readint          15             |  
| letrec           6              |  
| null             22             |  
| LE               10             |  
|-----|
```

Total cells 748

Collate function (interpreted)

Enter Expression

< 2, 3, 3, 5, 6, 6, 7,
3, 9, 10, 12>

Evaluation Completed

Statistics

System time was 633 milliseconds
User time was 11316 milliseconds

Purpose

Practical Application

Source Code

Result of Collate Function, Compiled

68

770	5	readint
827	1393	digit
835	1709	letter
843	313	readident
867	530	readval
879	6360	evcon
880	53265	evlis
881	23613	apply
882	5	letrec
884	70799	eval
947	5	letrec
1012	6360	evcon
1041	53265	evlis
1061	1115	membp
1071	666	memb
1083	1	isfinset
1093	18804	applyprim
1198	23613	apply
1239	28	dcprim
1261	1	readfname

Factorial function

Purpose Computes the factorial of n , where $n = 0, 1, 2, \dots$

Discussion

Factorial functions written in ELC and Pascal have been included to compare the relative efficiency of the interpreter versus a conventional high level language compiler. Factorial is computed for $n = 1$ to 10. The results are not surprising in that the Pascal version is much faster.

Source Code (ELC)

```
<letrec fact
  <lambda <n>
    <if <<call <var equal> <var n> <con 0>>
      <con 1>
      <call <var prod>
        <var n>
        <call <var fact>
          <call <var sub> <var n> <con 1>>>
      >>>>

  <call <var fact> <con 10>>
```

Results of ELC factorial function for $n = 1..10$

fact(0)

Enter Expression

1

Evaluation Completed

Statistics

System time was 83 milliseconds

User time was 233 milliseconds

```
-----
|Module          Cells created |
|-----|
```

dcprim	84	
cons	202	
readiden	30	
readint	4	
letrec	6	
equal	1	

Total cells 327

fact (1)

Enter Expression

1

Evaluation Completed

Statistics

System time was 83 milliseconds

User time was 266 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	212	
readiden	30	
readint	4	
letrec	6	
equal	2	
subt	1	
prod	1	

Total cells 340

fact (2)

Enter Expression

2

Evaluation Completed

Statistics

System time was 133 milliseconds
User time was 233 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	222	
readiden	30	
readint	4	
letrec	6	
equal	3	
subt	2	
prod	2	

Total cells 353

fact(3)

Enter Expression

6

Evaluation Completed

Statistics

System time was 133 milliseconds
User time was 266 milliseconds

Module	Cells created	
-----	-----	
dcprim	34	
cons	232	
readiden	30	
readint	4	

letrec	6	
equal	4	
subt	3	
prod	3	

Total cells	366
-------------	-----

fact (4)

Enter Expression

24

Evaluation Completed

Statistics

System time was 216 milliseconds

User time was 283 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	242	
readiden	30	
readint	4	
letrec	6	
equal	5	
subt	4	
prod	4	

Total cells	379
-------------	-----

fact (5)

Enter Expression

120

Evaluation Completed

Statistics

System time was 116 milliseconds
User time was 350 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	252	
readiden	30	
readint	4	
letrec	6	
equal	6	
subt	5	
prod	5	

Total cells 392

fact (6)

Enter Expression

720

Evaluation Completed

Statistics

System time was 116 milliseconds
User time was 416 milliseconds

Module	Cells created	
-----	-----	
dcprim	34	
cons	262	
readiden	30	
readint	4	
letrec	6	
equal	7	

subt	6	
prod	6	

Total cells	405
-------------	-----

fact (7)

Enter Expression

5040

Evaluation Completed

Statistics

System time was	133 milliseconds
-----------------	------------------

User time was	400 milliseconds
---------------	------------------

Module	Cells created	
-----	-----	
dcprim	84	
cons	272	
readiden	30	
readint	4	
letrec	6	
equal	8	
subt	7	
prod	7	

Total cells	418
-------------	-----

fact (8)

Enter Expression

40320

Evaluation Completed

Statistics

System time was	133 milliseconds
-----------------	------------------

User time was 433 milliseconds

Module	Cells created
dcprim	84
cons	282
readiden	30
readint	4
letrec	6
equal	9
subt	8
prod	8

Total cells 431

fact(9)

Enter Expression

362880

Evaluation Completed

Statistics

System time was 150 milliseconds

User time was 450 milliseconds

Module	Cells created
dcprim	84
cons	292
readiden	30
readint	4
letrec	6
equal	10
subt	9
prod	9

Total cells 444

fact(10)

Enter Expression

3623800

Evaluation Completed

Statistics

System time was 193 milliseconds

User time was 450 milliseconds

|Module Cells created |

|-----|

|ccprim 84 |

|cons 302 |

|readiden 30 |

|readint 4 |

|letrec 6 |

|equal 11 |

|subt 10 |

|prod 10 |

Total cells 457

Factorial function written in Berkely Pascal

Source Code

```
program fact(input, output);
  var ans,n:integer;

  function factorial(n:integer):integer;
    var fact:integer;
    begin
      if n = 0 then
        fact := 1
      else
        fact := n * (factorial (n - 1));
      factorial := fact;
    end; {function factorial}

  begin
    writeln('Input n: ');
    readln(n);
    ans := factorial(n);
    writeln(ans);
    writeln('System Clock ',sysclock:10 ,' millisec');
    writeln('User Clock   ',clock:10 ,' millisec');
  end. {Program fact}
```

Results of factorial function in Berkeley Pascal, n= 1..10.

Input n=0

1

System Clock	33 millisec
User Clock	16 millisec

Input n=1

1

System Clock	33 millisec
User Clock	0 millisec

Input n=2

2

System Clock 33 milliseC

User Clock 0 milliseC

Input n=3

6

System Clock 33 milliseC

User Clock 0 milliseC

Input n=4

24

System Clock 33 milliseC

User Clock 0 milliseC

Input n=5

120

System Clock 33 milliseC

User Clock 0 milliseC

Input n=6

720

System Clock 33 milliseC

User Clock 0 milliseC

Input n=7

5040

System Clock 16 milliseC

User Clock 16 milliseC

Input n=8

40320

System Clock 33 millisec

User Clock 0 millisec

Input n=9

362880

System Clock 33 millisec

User Clock 0 millisec

Input n=10

3628800

System Clock 66 millisec

User Clock 16 millisec

Profile for ELC factorial function

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:43 1984 test11.p

Profiled Thu Dec 13 09:56 1984

Line	Count	
1	1	func
33	1	printval
36	401	cellcount
62	11	equal
63	954	nullp
84	2064	first
94	1132	rest
122	302	cons
183	10	subt
208	10	prod
272	11	equalp
291	11	equal
533	150	atomp

547	954	nullp
599	73	assoc
643	22	pairlis
663	1	printval
702	56	readval
704	78	nonblank
714	22	readlist
741	0	readrea
770	4	readint
827	129	digit
835	163	letter
843	30	readident
867	56	readval
879	11	evcon
880	115	evlis
881	42	apply
882	1	letrec
884	150	eval
947	1	letrec
1012	11	evcon
1041	115	evlis
1093	31	applyprim
1198	42	apply
1239	28	dcprim
1261	1	readfname

Fibonacci Sequence Generation Program (No 'let' statement)

Purpose

This program generates the first n elements of the fibonacci sequence.

Discussion

This function is educational in that it shows how efficiency of ELC programs can be improved through the use of the 'let' statement. The definition of the Fibonacci sequence is:

```
fib(1) = <1>
fib(2) = <1 1>
fib(n = 3, 4, ...) =
  cons ((fib(n-1)sub 1) + (fib(n-2)sub 2)), fib(n-1)),
  where sub 1, 2 means subscript.
```

The time consuming part of this function, when written in ELC, is calculating fib of n-1 three times to find the next element of the sequence. This can be avoided by using a let statement to calculate fib(n-1) only once for each iteration. The system time taken to generate fib(10) when using the let statement was approximately .2 seconds compared to 13 seconds when a 'let' was not used. This is not surprising since when not using the 'let' the time of execution will increase exponentially as n increases.

Notice also that due to the nature of recursive construction of lists the sequence is constructed in reverse order. To correct this the reverse function is included and applied to the generated sequence before printing.

Source Code

```
<letrec reverse
  <lambda <L>
    <if <<call <var null> <var L>>>
      <con <>>
```

AD-A155 218

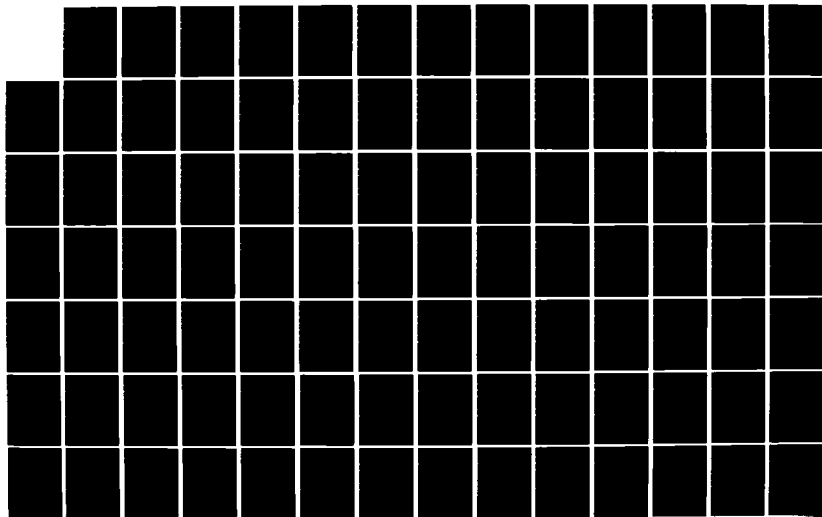
A PASCAL INTERPRETER FOR THE FUNCTIONAL PROGRAMMING
LANGUAGE ELC (EXTENDED LAMBDA CALCULUS)(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA R P STEEN DEC 84

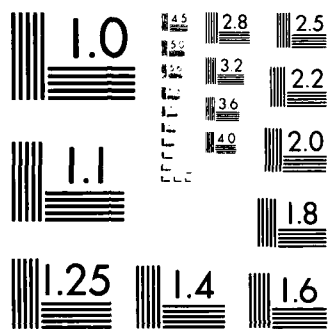
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

```

        <call <var contr>
            <call <var reverse>
                <call <var rest> <var L>>>
                <call <var sub> <var L> <con 1>> >>>>
<letrec fibo
  <lambda <n>
    <if <<call <var equal> <var n> <con 0>>
      <con <>>
      <if <<call <var equal> <var n> <con 1>>
        <con <1>>
        <if <<call <var equal> <var n> <con 2>>
          <ccn <1 1>>
          <call <var ccns>
            <call <var sum>
              <call <var sub>
                <call <var fibo>
                  <call <var subt>
                    <var n>
                    <con 1>>>
                <con 1>>
              <call <var sub>
                <call <var fibo>
                  <call <var subt>
                    <var n>
                    <con 1>>>
                <con 2>>>
            <call <var fibo>
              <call <var subt> <var n> <con 1>>>>
              >>>>>>
        <call <var reverse>
          <call <var fibo> <con 10>>>>>!
```

Results of fib(3..10) without a let statement

fib(3)

Enter Expression

< 1, 1, 2>

Evaluation Completed

Statistics

System time was 183 milliseconds
User time was 733 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	428	
readiden	105	
readint	11	
letrec	12	
equal	12	
subt	3	
sum	1	
null	4	
conr	2	

Total cells 662

fib(4)

Enter Expression

< 1, 1, 2, 3>

Evaluation Completed

Statistics

System time was 166 milliseconds
User time was 1250 milliseconds

```

-----
|Module          Cells created |
|-----|
|dcprim          84           |
|cons            570          |
|readiden        105          |
|readint          11          |
|letrec           12          |
|equal            39          |
|subt             12          |
|sum              4           |
|null            5           |
|conr             3           |
-----

```

```

Total cells      845

```

```

fib(5)

```

```

Enter Expression

```

```

< 1, 1, 2, 3, 5>

```

```

Evaluation Completed

```

```

*****

```

Statistics

```

System time was      216 milliseconds

```

```

User time was        2566 milliseconds

```

```

-----
|Module          Cells created |
|-----|
|dcprim          84           |
|cons            976          |
|readiden        105          |
|readint          11          |
|letrec           12          |
|equal            120          |
|subt             39          |

```

sum	13	
null	6	
conr	4	

Total cells 1370

fib(6)

Enter Expression

< 1, 1, 2, 3, 5, 8>

Evaluation Completed

Statistics

System time was 300 milliseconds

User time was 6350 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	2174	
readiden	105	
readint	11	
letrec	12	
equal	363	
subt	120	
sum	40	
null	7	
conr	5	

Total cells 2921

fib(7)

Enter Expression

< 1, 1, 2, 3, 5, 8, 13>

Evaluation Completed

Statistics

System time was 666 milliseconds
User time was 17766 milliseconds

```
-----  
|Module      Cells created |  
|-----  
|dcprim      84           |  
|cons        5748          |  
|readiden    105           |  
|readint     11            |  
|letrec      12            |  
|equal       1092          |  
|subt        363           |  
|sum         121           |  
|null        8             |  
|conr        6             |  
-----
```

Total cells 7550

fib(8)

Enter Expression

< 1, 1, 2, 3, 5, 8, 13,
21>

Evaluation Completed

Statistics

System time was 1633 milliseconds
User time was 51716 milliseconds

```
-----  
|Module      Cells created |  
|-----  
|-----  
|-----
```

dcprim	84	
cons	16450	
readiden	105	
readint	11	
letrec	12	
equal	3279	
subt	1092	
sum	364	
null	9	
conr	7	

Total cells	21413
-------------	-------

fib(9)

Enter Expression

< 1, 1, 2, 3, 5, 8, 13,
21, 34>

Evaluation Completed

Statistics

System time was	4650 milliseconds
User time was	154450 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	48536	
readiden	105	
readint	11	
letrec	12	
equal	9840	
subt	3279	
sum	1093	
null	10	

|conr 8 |

Total cells 62978

fib(10)

Enter Expression

< 1, 1, 2, 3, 5,
8, 13, 21, 34, 55>

Evaluation Completed

Statistics

System time was 13100 milliseconds

User time was 458983 milliseconds

|Module Cells created |

|-----|

|dcprim 84 |

|cons 144774 |

|readiden 105 |

|readint 11 |

|letrec 12 |

|equal 29523 |

|subt 9840 |

|sum 3280 |

|null 11 |

|conr 9 |

Total cells 187649

ELC Program to generate the Fikonacci Sequence (Using a let statement)

Source Code

```
<letrec reverse
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var cons>
        <call <var reverse>
          <call <var rest> <var L>>>
        <call <var sub> <var L> <con 1>>>>>>
  <letrec fibo
    <lambda <n>
      <if <<call <var equal> <var n> <con 0>>
        <con <>>
        <if <<call <var equal> <var n> <con 1>>
          <con <1>>
          <if <<call <var equal> <var n> <con 2>>
            <con <1 1>>
            <let <<f> <<call <var fibo>
              <call <var sub>
                <var n>
                <con 1>>>>
              <call <var cons>
                <call <var sum>
                  <call <var first>
                    <var f>>
                  <call <var first>
                    <call <var rest>
                      <var f>>>>
                <var f>>>>>>>>>>>>
            <call <var reverse>
              <call <var fibo> <con 10>>>>>>!
```

Results of fibonacci generating function with 'let'
statement

fib (3..10)

fib(3)

Enter Expression

< 1, 1, 2>

Evaluation Completed

Statistics

System time was 133 milliseconds

User time was 700 milliseconds

```
-----  
|Module          Cells created |  
|-----|  
|dcprim          84          |  
|cons            392         |  
|readiden        95          |  
|readint          9          |  
|letrec          12          |  
|equal           6           |  
|subt             1          |  
|sum              1          |  
|null            4           |  
|conr            2           |  
|-----|
```

Total cells 606

fib(4)

Enter Expression

< 1, 1, 2, 3>

Evaluation Completed

	Statistics
System time was	183 milliseconds
User time was	783 milliseconds

```

-----
|Module          Cells created |
|-----|
|dcprim          84           |
|cons            427          |
|readiden        95           |
|readint         9            |
|letrec          12           |
|equal           9            |
|subt            2            |
|sum             2            |
|null            5            |
|conr            3            |

```

```

-----
Total cells      648

```

fib(5)

Enter Expression

< 1, 1, 2, 3, 5>

Evaluation Completed

	Statistics
System time was	166 milliseconds
User time was	866 milliseconds

```

-----
|Module          Cells created |
|-----|
|dcprim          84           |
|cons            462          |
|readiden        95           |

```

readint	9	
letrec	12	
equal	12	
subt	3	
sum	3	
null	6	
conr	4	

Total cells	690
-------------	-----

fib(6)

Enter Expression

< 1, 1, 2, 3, 5, 8>

Evaluation Completed

Statistics

System time was 133 milliseconds

User time was 1066 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	497	
readiden	95	
readint	9	
letrec	12	
equal	15	
subt	4	
sum	4	
null	7	
conr	5	

Total cells	732
-------------	-----

fib(7)

Enter Expression

< 1, 1, 2, 3, 5, 8, 13>

Evaluation Completed

Statistics

System time was 183 milliseconds

User time was 1100 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	532	
readiden	95	
readint	9	
letrec	12	
equal	18	
subt	5	
sum	5	
null	8	
conr	6	

Total cells 774

fib(8)

Enter Expression

1, 1, 2, 3, 5, 8, 13,
1>

Evaluation Completed

Statistics

System time was 183 milliseconds

User time was 1216 milliseconds

|len 3 |

Total cells 1218

Results of restriction (interpreted)

Enter Expression

<< 6, 5>
, < 8, 9>
>

Evaluation Completed

Statistics

System time was 516 milliseconds

User time was 17966 milliseconds

|Module Cells created |

|-----|

|dcprim 84 |

|cons 837 |

|readiden 220 |

|readint 8 |

|letrec 24 |

|eval 1 |

|equal 12 |

|null 29 |

|len 3 |

Total cells 1218

Profile for restriction program

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

```

                                <call <var first>
                                <var T>>>>
    <call <var rest> <var T>>
    <call <var cons>
        <call <var first> <var T>>
        <call <var restric>
            <call <var rest> <var T>>
            <var k>>>>
    <con Tnotffunc>>>>>>>>
<call <var restric>
    <call <var repr> <finset <3 4> <6 5> <8 9>> >
    <con 3> >>>>>>>>!
```

Results of restriction function (Compiled)

Enter Expression

```

<<      6,      5>
, <      8,      9>
>
```

Evaluation Completed

Statistics

```

System time was      216 milliseconds
User time was        1966 milliseconds
```

```

-----
|Module           Cells created |
|-----|
|dcprim              84         |
|cons              837         |
|readiden           220         |
|readint              8         |
|letrec             24         |
|eval                1         |
|equal             12         |
|null              29         |
```

```

    <con true>
    <if <<call <var equal>
        <call <var len>
            <call <var first> <var T>>>
        <con 2>>
    <if <<call <var equal>
        <call <var member>
            <call <var first>
                <call <var firstlist>
                    <var T>>>
            <call <var rest>
                <call <var firstlist>
                    <var T>>>>
        <con true>>
    <con false>
    <call <var isfinfunc>
        <call <var rest>
            <var T>>>>>
    <con false>>>>>
<let <<repr> <<lambda <T>
    <if <<call <var equal>
        <call <var first> <var T>>
        <con finset>>
        <call <var rest> <var T>>
        <con nofinfunc>>>>>
<letrec restric
    <lambda <T k>
        <if <<call <var equal>
            <call <var isfinfunc> <var T>>
            <con true>>
        <if <<call <var null> <var T>>
            <con <>>
            <if <<call <var equal>
                <var k>
                <call <var first>

```

Restriction

Purpose

Restriction takes a finite function, T, (table of attribute value pairs), and returns a finite function exactly like T except that one of the pairs has been removed. If the pair to be deleted is not a member of the finite function then T is returned (this is tolerant evaluation).

Practical Application Restriction could be used to delete records from a database.

Source Code

```
<letrec member
  <lambda <x L>
    <if <<call <var null> <var L>>
      <con false>
      <if <<call <var equal>
        <var x>
        <call <var first> <var L>>>
        <con true>
        <call <var member>
          <var x>
          <call <var rest> <var L>>>>>>>>
    <con false>
  </lambda>
</letrec>

<letrec firstlist
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var cons>
        <call <var first>
          <call <var first> <var L>>>
        <call <var firstlist>
          <call <var rest> <var L>>>>>>>>
    <con <>>
  </lambda>
</letrec>

<letrec isfinfunc
  <lambda <T>
    <if <<call <var null> <var T>>
      <con false>
      <call <var member>
        <call <var first> <var T>>
        <call <var isfinfunc>
          <call <var rest> <var T>>>>>>>>
    <con true>
  </lambda>
</letrec>
```

880	606	evlis
881	202	apply
882	1	letrec
884	761	eval
947	1	letrec
1012	51	evcon
1041	606	evlis
1093	151	applyprim
1198	202	apply
1239	28	dcprim
1261	1	readfname

|sum 50 |

Total cells 1192

Profile for interval function m, n 1-50

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.f

Profiled Thu Dec 13 13:54 1984

Line	Count	func
1	1	
33	51	printval
36	1136	cellcount
63	5487	nullp
84	11793	first
94	6357	rest
122	963	cons
158	50	sum
330	51	GTp
340	51	GT
539	761	atomp
547	5487	nullp
599	454	assoc
643	153	pairlis
663	51	printval
702	63	readval
704	88	nonblank
714	25	readlist
770	3	readint
827	151	digit
835	189	letter
843	35	readident
867	63	readval
879	51	evcon

Evaluation Completed

Statistics

System time was 266 milliseconds
User time was 1716 milliseconds

```
-----  
|Module          Cells created |  
|-----|  
|dcprim          84          |  
|cons            963         |  
|readiden        35          |  
|readint         3           |  
|letrec          6           |  
|GT              51          |  
|sum             50          |  
-----
```

Total cells 1192

Results of interval (interpreted)

Statistics

System time was 616 milliseconds
User time was 19966 milliseconds

```
-----  
|Module          Cells created |  
|-----|  
|dcprim          84          |  
|cons            963         |  
|readiden        35          |  
|readint         3           |  
|letrec          6           |  
|GT              51          |  
-----
```

Interval Generating Function

Purpose

Generates a sequence of natural numbers from m to n , where m, n are two natural numbers and $m < n$.

Practical Application

Interval is very useful when generating tables of information. In the next example interval is used to generate a table of trigonometric values for all angles between 0 and 90 degrees.

Source Code

```
<letrec interval
  <lambda <m n>
    <if <<call <var GT> <var m> <var n>>
      <con <>>
      <call <var cons>
        <var m>
        <call <var interval>
          <call <var sum>
            <var m> <con 1>>
            <var n>> >>>>
    <call <var interval> <con 1> <con 50>>>>!
```

Results of interval generation program ($m = 1$, $n = 50$,
Compiled)

Enter Expression

```
<      1,      2,      3,      4,      5,      6,      7,
      8,      9,     10,     11,     12,     13,     14,
     15,     16     17,     18,     19,     20,     21,
     22,     23,     24     25,     26,     27,     28,
     29,     30,     31,     32     33,     34,     35,
     36,     37,     38,     39,     40     41,     42,
     43,     44,     45,     46,     47,     48,     49,
     50>
```

539	466	atomp
547	3862	nullp
564	11	null
599	226	assoc
643	56	pairlis
663	11	printval
702	180	readval
704	256	nonblank
714	76	readlist
770	9	readint
827	410	digit
835	514	letter
843	95	readident
867	180	readval
879	38	evcon
880	375	evlis
881	136	apply
882	2	letrec
884	466	eval
947	2	letrec
1012	38	evcon
1041	375	evlis
1093	116	applyprim
1198	136	apply
1239	28	dcprim
1261	1	readfname

Use: ime 0 millisec

fib(5)

Input n:

1	1	2	3	5
8	13	21	34	

System time 33 millisec

User time 0 millisec

fib(10)

Input n:

1	1	2	3	5
8	13	21	34	55

System time 33 millisec

User time 0 millisec

Profile for ELC fibonacci sequence generating functions

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.f

Profiled Thu Dec 13 09:41 1984

Line	Count	func
1	1	
33	11	printval
36	844	cellcount
62	27	equal
63	3862	nullp
84	8188	first
94	4372	rest
122	637	cons
137	10	conr
158	8	sum
183	8	subt
258	10	sub
273	27	equalp
291	27	equal

fib(3)

Input n:

1	1	2
System time	33	millisec
User time	0	millisec

fib(4)

Input n:

1	1	2	3
System time	50	millisec	
User time	0	millisec	

fib(5)

Input n:

1	1	2	3	5
System time	33	millisec		
User time	0	millisec		

fib(6)

Input n:

1	1	2	3	5
8				
System time	33	millisec		
User time	0	millisec		

fib(7)

Input n:

1	1	2	3	5
8	13			
System time	33	millisec		
User time	0	millisec		

fib(8)

Input n:

1	1	2	3	5
8	13	21		
System time	33	millisec		

Pascal Source Code for Fibonacci Sequence Generator

```
program fib(input, output);
  const max =100;
  type seq = 1..max of integer;
  var fibseq: seq;
      n,c: integer;

  procedure fib(n,i:integer);
    begin
      if i <= n then begin
        if (i = 1) or (i = 2) then begin
          fibseq(.i.) := 1;
          fib(n,i + 1);
        end
        else if i >= 3 then begin
          fibseq(.i.) := fibseq(.i-1.) + fibseq(.i-2.);
          fib(n,i + 1);
        end
      end;
    end; {procedure fib}

  begin
    writeln('Input n: ');
    read(n);
    fib(n,1);
    for c := 1 to max do begin
      if fibseq(.c.) <> 0 then
        write (fibseq(.c.));
      end;
    writeln;
    writeln('System time',sysclock:10,' millisec');
    writeln('User time ',clock:10,' millisec');
  end. {Program fib}
```

Results of fibonacci sequence generator in Pascal

equal	24	
subt	7	
sum	7	
null	10	
conr	8	

Total cells	858
-------------	-----

fib(10

Enter Expression

< 1, 1, 2, 3, 5,
8, 13, 21, 34, 55>

Evaluation Completed

Statistics

Syster time was 166 milliseconds

User time was 1466 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	637	
readiden	95	
readint	9	
letrec	12	
equal	27	
subt	8	
sum	8	
null	11	
conr	9	

Total cells	900
-------------	-----

Module	Cells created	
dcprim	84	
cons	567	
readiden	95	
readint	9	
letrec	12	
equal	21	
subt	6	
sum	6	
null	9	
conr	7	

Total cells 816

fib(9)

Enter Expression

< 1, 1, 2, 3, 5, 8, 13,
21, 34>

Evaluation Completed

Statistics

System time was 200 milliseconds

User time was 1300 milliseconds

Module	Cells created	
dcprim	84	
cons	602	
readiden	95	
readint	9	
letrec	12	

Profiled Thu Dec 13 14:50 1984

Line	Count	func
1	1	
33	7	printval
36	1162	cellcount
62	12	equal
63	4184	nullp
84	8859	first
94	4699	rest
122	837	cons
273	12	equalp
291	12	equal
539	441	atomp
547	4184	nullp
564	29	null
576	9	lenp
587	3	len
599	228	assoc
643	69	pairlis
663	7	printval
702	387	readval
704	546	nonblank
714	159	readlist
770	8	readint
827	1011	digit
835	1239	letter
843	220	readident
879	41	evcon
880	325	evlis
881	145	apply
882	4	letrec
884	441	eval
947	4	letrec
1012	41	evcon

1041	325	evlis
1093	115	applyprim
1198	145	apply
1239	28	dcprim
1261	1	readfname

Vectorproduct Function

Purpose

Vectorproduct returns the pairwise products of two lists of numbers.

Practical Application

This function could be used to calculate the state tax owed by military employees, since different states have different rates of taxation. One vector would be the list of salaries and the other the rates of taxation.

Source Code

```
<letrec map
  <lambda <f>
    <lambda <L>
      <if <<call <var null> <var L>>
        <con <>>
        <call <var cons>
          <call <var f> <call <var first><var L>>>
          <call <call <var map> <var f>>
          <call <var rest> <var L>>>>>>>>
      <call <var prodlist>
        <lambda <L>
          <if <<call <var null> <var L>>
            <con 1>
            <call <var prod>
              <call <var sub> <var L> <con 1>>
              <call <var prodlist>
                <call <var rest> <var L>>>>>>>>
          <call <var pairlist>
            <lambda <L M>
              <if <<call <var equal>
                <call <var len> <var L>>
                <call <var len> <var M>>>
                <if <<call <var null> <var L>>
```

```

        <if <<call <var null> <var M>>
            <con <>>
            <con <>>>>
        <call <var cons>
            <call <var cons>
                <call <var first> <var L>>
                <call <var cons>
                    <call <var first> <var M>>
                    <con <>> >>
            <call <var pairlist>
                <call <var rest> <var L>>
                <call <var rest> <var M>>>>>>>>
        <con errorpl> >>>
<call
    <call <var map> <var prodlist>>
        <call <var pairlist>
            <list <con 5> <con 8> <con 4> <con 9>>
            <list <con 2> <con 20> <con 7> <con 3>>>>>>>>!
```

Results of vectorprd function (Compiled)

Enter Expression

< 10, 160, 28, 27>

Evaluation Completed

Statistics

System time was 216 milliseconds

User time was 1593 milliseconds

```

-----
|Module          Cells created |
|-----|
|dcprim          84           |
|cons            720          |
|readiden        150          |
|readint         10           |
```

letrec	18	
len	10	
equal	5	
null	23	
eval	5	
prod	8	

Total cells	1033
-------------	------

Results of vectorproduct function (Interpreted)

Enter Expression

< 10, 160, 28, 27>

Evaluation Completed

Statistics

System time was 483 milliseconds

User time was 15066 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	720	
readilen	150	
readint	10	
letrec	18	
eval	5	
len	10	
equal	5	
null	23	
prod	8	

Total cells	1033
-------------	------

Profile for vectorproduct function

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.f

Profiled Thu Dec 13 15:09 1984

line	Count	func
1	1	
33	5	printval
36	977	cellcount
62	5	equal
63	3579	nullp
84	7535	first
94	4038	rest
122	720	cons
208	8	prod
258	8	sub
273	5	equalp
291	5	equal
539	395	atomp
547	3579	nullp
564	23	null
576	30	lenp
587	10	len
599	202	assoc
643	59	pairlis
663	5	printval
702	272	readval
704	384	nonblank
714	112	readlist
770	10	readint
827	659	digit
835	819	letter
843	150	readident

867	272	readval
879	28	evcon
880	310	evlis
881	129	apply
882	3	letrec
884	395	eval
947	3	letrec
1012	28	evcon
1041	310	evlis
1093	102	applyprim
1198	129	apply
1239	28	dcprim
1261	1	readfname

Filter Function

Purpose

Filter allows the user to extract information from a list based on a Boolean condition. In the example given, all numbers greater than 2000 are extracted from the list.

Practical Application

Filter is another function that could be useful when dealing with databases. Users of relational database systems use filtering every time they write a query. Imagine that the elements of the example are salaries. The query demonstrated is to find all salaries greater than 2000.

Source Code

```
<letrec fil
  <lambda <bool arg>
    <lambda <L>
      <if <<call <var null> <var L>>
        <con <>>
        <if <<call <var bcol>
          <call <var sub> <var L>
          <con 1>>
          <var arg>>
          <call <var ccns>
            <call <var sub> <var L> <con 1>>
            <call <call <var fil>
              <var bool>
              <var arg>>
              <call <var rest> <var L>>>>
            <call <call <var fil>
              <var bool>
              <var arg>>
              <call <var rest> <var L>>>>>>>>>>>>
          <call

```

```

<call <var fil> <var GE> <ccn 2000>>
<list <con 1000> <ccn 12000> <con 2005> <con 3400>
      <con 3305> <con 134> <con 2001> <con 3500>
      <con 2209> <ccn 1999>>>>!
```

Results of filter function(Interpreted)

Enter Expression

```
< 12000, 2005, 3400, 3305, 2001, 3500, 2209>
```

Evaluation Completed

Statistics

System time was 416 milliseconds

User time was 9083 milliseconds

```

-----
|Module          Cells created |
|-----|
|dcprim          84           |
|cons            562          |
|readiden        79           |
|readint         13           |
|letrec          6            |
|eval            11           |
|null            11           |
|GE              10           |
|-----|
```

```
Total cells      776
```

Result of filter function (Compiled)

Enter Expression

```
< 12000, 2005, 3400, 3305, 2001, 3500, 2209>
```

Evaluation Completed

Statistics

System time was 216 milliseconds
 User time was 816 milliseconds

Module	Cells created
dcprim	84
cons	562
readiden	79
readint	13
letrec	6
eval	11
null	11
GE	10
Total cells	776

Profile for the filtering function

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 13:40 1984

Line	Count	
1	1	func
33	8	printval
36	720	cellcount
63	1838	nullp
84	4010	first
94	2185	rest
122	562	cons
258	17	sub
357	10	GEp
367	10	GE
539	275	atomp

547	1838	nullp
564	11	null
599	135	assoc
643	55	pairlis
663	9	printval
702	151	readval
704	210	nonblank
714	59	readlist
770	13	readint
827	332	digit
835	424	letter
843	79	readident
867	151	readval
879	21	evcon
880	210	evlis
881	77	apply
882	1	letrec
884	275	eval
947	1	letrec
1012	21	evcon
1041	210	evlis
1093	55	applyprim
1198	77	apply
1239	28	dcprim
1261	1	readfname

Periodic Sequence Generator

Purpose

This program simply illustrates the interpreter's ability to generate a recursive sequence.

Source Code

```
<letrec reverse
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var conr>
        <call <var reverse>
          <call <var rest> <var L>>>
        <call <var sub> <var L> <con 1>>>>>>
  <letrec fibo
    <lambda <n>
      <if <<call <var equal> <var n> <con 1>>
        <con <2>>
        <if <<call <var equal> <var n> <con 2>>
          <ccn <9 2>>
          <let <<f> <<call <var fibo>
            <call <var sub>
              <var n>
              <con 1>>>>
            <call <var cons>
              <call <var sub>
                <call <var first>
                  <var f>>
                <call <var first>
                  <call <var rest>
                    <var f>>>>
              <var f>>>>>>>>
          <call <var reverse>
            <call <var fibo> <con 24>>>>>>!
```

Results of generating the first 24 elements of a periodic sequence, where $x_1 = 2$, $x_2 = 9$, and $x_k = (x_{k-1}) - (x_{k-2})$ for $k = 3, 4, 5, \dots$

Enter Expression

```
<  2,      9,      7,      -2,      -9,      -7,
    2,      9,      7,      -2,      -9,      -7,
    2,      9,      7,      -2,      -9,      -7,
    2,      9,      7,      -2,      -9,      -7>
```

Evaluation Completed

Statistics

System time was 283 milliseconds
User time was 2916 milliseconds

```
-----
|Module      Cells created |
|-----|
|dcprim      84           |
|cons      1064          |
|readiden    87           |
|readint      8           |
|letrec     12            |
|equal       46           |
|subt        44           |
|null        25           |
|conr        23           |
|-----|
```

Total cells 1393

Profile of seq2 (periodic function)

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 10:10 1984

Line	Count	func
1	1	
33	21	printval
36	1181	cellicount
62	38	equal
63	7652	nullp
84	16163	first
94	8626	rest
122	932	cons
137	20	conr
183	36	subt
258	20	sub
273	38	equalp
291	38	equal
539	881	atomp
547	7652	nullp
564	21	null
599	438	assoc
643	116	pairlis
663	21	printval
702	163	readval
704	231	nonblank
714	68	readlist
779	8	readint
827	379	digit
835	474	letter
843	87	readident
867	163	readval
879	59	evcon
880	738	evlis
881	267	apply
882	2	letrec
884	881	eval
947	2	letrec

, < 44, 0.694658, 0.719340, 0.965689>
 , < 45, 0.707107, 0.707107, 1.000000>
 , < 46, 0.719340, 0.694658, 1.035530>
 , < 47, 0.731354, 0.681998, 1.072369>
 , < 48, 0.743145, 0.669131, 1.110613>
 , < 49, 0.754710, 0.656059, 1.150368>
 , < 50, 0.766044, 0.642788, 1.191754>
 , < 51, 0.777146, 0.629320, 1.234897>
 , < 52, 0.788011, 0.615661, 1.279942>
 , < 53, 0.798636, 0.601815, 1.327045>
 , < 54, 0.809017, 0.587785, 1.376382>
 , < 55, 0.819152, 0.573576, 1.428148>
 , < 56, 0.829038, 0.559193, 1.482561>
 , < 57, 0.838671, 0.544639, 1.539865>
 , < 58, 0.848048, 0.529919, 1.600335>
 , < 59, 0.857167, 0.515038, 1.664279>
 , < 60, 0.866025, 0.500000, 1.732051>
 , < 61, 0.874620, 0.484810, 1.804048>
 , < 62, 0.882948, 0.469472, 1.880726>
 , < 63, 0.891007, 0.453990, 1.962611>
 , < 64, 0.898794, 0.438371, 2.050304>
 , < 65, 0.906308, 0.422618, 2.144507>
 , < 66, 0.913545, 0.406737, 2.246037>
 , < 67, 0.920505, 0.390731, 2.355852>
 , < 68, 0.927184, 0.374607, 2.475087>
 , < 69, 0.933580, 0.358368, 2.605089>
 , < 70, 0.939693, 0.342020, 2.747477>
 , < 71, 0.945519, 0.325568, 2.904211>
 , < 72, 0.951057, 0.309017, 3.077684>
 , < 73, 0.956305, 0.292372, 3.270853>
 , < 74, 0.961262, 0.275637, 3.487414>
 , < 75, 0.965926, 0.258819, 3.732051>
 , < 76, 0.970296, 0.241922, 4.010781>
 , < 77, 0.974370, 0.224951, 4.331476>
 , < 78, 0.978148, 0.207912, 4.704630>

, < 9, 0.156434, 0.987688, 0.158384>
 , < 10, 0.173648, 0.984808, 0.176327>
 , < 11, 0.190809, 0.981627, 0.194380>
 , < 12, 0.207912, 0.978148, 0.212557>
 , < 13, 0.224951, 0.974370, 0.230868>
 , < 14, 0.241922, 0.970296, 0.249328>
 , < 15, 0.258819, 0.965926, 0.267949>
 , < 16, 0.275637, 0.961262, 0.286745>
 , < 17, 0.292372, 0.956305, 0.305731>
 , < 18, 0.309017, 0.951057, 0.324920>
 , < 19, 0.325568, 0.945519, 0.344328>
 , < 20, 0.342020, 0.939693, 0.363970>
 , < 21, 0.358368, 0.933580, 0.383864>
 , < 22, 0.374607, 0.927184, 0.404026>
 , < 23, 0.390731, 0.920505, 0.424475>
 , < 24, 0.406737, 0.913545, 0.445229>
 , < 25, 0.422618, 0.906308, 0.466308>
 , < 26, 0.438371, 0.898794, 0.487733>
 , < 27, 0.453990, 0.891007, 0.509525>
 , < 28, 0.469472, 0.882948, 0.531709>
 , < 29, 0.484810, 0.874620, 0.554309>
 , < 30, 0.500000, 0.866025, 0.577350>
 , < 31, 0.515038, 0.857167, 0.600861>
 , < 32, 0.529919, 0.848048, 0.624869>
 , < 33, 0.544639, 0.838671, 0.649408>
 , < 34, 0.559193, 0.829038, 0.674509>
 , < 35, 0.573576, 0.819152, 0.700208>
 , < 36, 0.587785, 0.809017, 0.726543>
 , < 37, 0.601815, 0.798636, 0.753554>
 , < 38, 0.615661, 0.788011, 0.781286>
 , < 39, 0.629320, 0.777146, 0.809784>
 , < 40, 0.642788, 0.766044, 0.839100>
 , < 41, 0.656059, 0.754710, 0.869287>
 , < 42, 0.669131, 0.743145, 0.900404>
 , < 43, 0.681998, 0.731354, 0.932515>

```

        <var x>>
        <call
            <call <var pam>
                <call <var rest><var F>>>
                <var x>>>>>>>
<letrec interval
    <lambda <m n>
        <if <<call <var GT> <var m> <var n>>
            <con <>>
            <call <var cons>
                <var m>
                <call <var interval>
                    <call <var sum>
                        <var m>
                        <con 1>>
                    <var n>> >>>>
<call
    <call <var map>
        <call <var pam> <list <var id> <var sin>
            <var cos> <var tan>>>>
<call <var interval> <con 0> <con 90>>>>>>>!
```

Results of mapping the pam function across a list to generate the table of trigonometric values for angles 0 - 90 degrees.

Enter Expression

```

<<      0, 0.000000, 1.000000, 0.000000>
, <      1, 0.017452, 0.999848, 0.017455>
, <      2, 0.034899, 0.999391, 0.034921>
, <      3, 0.052336, 0.998630, 0.052408>
, <      4, 0.069756, 0.997564, 0.069927>
, <      5, 0.087156, 0.996195, 0.087489>
, <      6, 0.104528, 0.994522, 0.105104>
, <      7, 0.121869, 0.992546, 0.122785>
, <      8, 0.139173, 0.990268, 0.140541>
```

Trig Table Generating Program

Purpose

Generates a table of trigonometric values for all angles in the interval 0 to 90 degrees.

Discussion

This program demonstrates the value of the interval function combined with the map functional. The reverse of the map functional, (pam), is also used. Map takes one function and applies it to all the elements of a list, where pam takes a list of functions and applies each one to the same argument. It is clear that mapping the pam function across the interval 0 to 90 produces the desired results. This program also illustrates the value of the 'id' primitive which allows the first element of each of the sublists in the result to be the angle.

Source Code

```
<letrec map
  <lambda <f>
    <lambda <L>
      <if <<call <var null> <var L>>
        <con <>>
        <call <var cons>
          <call <var f> <call <var first><var L>>>
          <call <call <var map> <var f>>
          <call <var rest> <var L>>>>>>>>
    <letrec pam
      <lambda <F>
        <lambda <x>
          <if <<call <var null> <var F>>
            <con <>>
            <call <var cons>
              <call
                <call <var first> <var F>>
```

947	1	letrec
1012	6	evcon
1041	169	evlis
1093	45	applyprim
1198	52	apply
1239	28	dcprim
1261	1	readfname

Profiled Thu Dec 13 15:03 1984

Line	Count	func
1	1	
33	13	printval
36	614	cellcount
62	6	equal
63	1656	nullp
84	3439	first
94	1861	rest
122	472	cons
183	5	subt
233	1	divi
273	6	equalp
291	6	equal
539	183	atomp
547	1656	nullp
576	11	lenp
587	1	len
599	86	assoc
643	32	pairlis
663	13	printval
702	156	readval
704	218	nonblank
714	62	readlist
770	3	readint
827	375	digit
835	469	letter
843	91	readident
867	156	readval
879	6	evcon
880	169	evlis
881	52	apply
882	1	letrec
884	183	eval

<var L>>>>

<call <var split> <list a b c d e f i o e t>>>>>!

Results of using the split function to divide a 10 element list

Enter Expression

<<a, b, c, d, e>
, <f, i, o, e, t>
>

Evaluation Completed

Statistics

System time was 166 milliseconds
User time was 833 milliseconds

Module	Cells created	
-----	-----	
dcprim	84	
cons	472	
readiden	91	
readint	3	
letrec	6	
eval	1	
len	1	
divi	1	
equal	6	
subt	5	

Total cells 670

Profile of split (ten element list)

Berkeley Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.f

Split Function

Purpose

Split takes a list and divides it into two equal size lists.

Practical Application

The split function illustrates how functional languages lend themselves to parallel computer operations. If quicksort was implemented using split then once the list was initially separated into two lists, two processors could work on those two lists, etc..

Source Code

```
<letrec splitaux
  <lambda <k L>
    <if <<call <var equal> <var k> <con 0>>>
      <call <var cons>
        <con <>>
        <call <var cons>
          <var L>
          <con <>>>>
      <let <<r> <<call <var splitaux>
        <call <var subt> <var k> <con 1>>
        <call <var rest> <var L>>>>
        <call <var cons>
          <call <var cons>
            <call <var first> <var L>>
            <call <var first> <var r>>>
            <call <var rest> <var r>>>>>>>>
    <let <<split>
      <<lambda <L>
        <call <var splitaux>
          <call <var divi>
            <call <var len> <var L>>
            <con 2>>
```

122	907	cons
273	17	equalp
291	13	equal
539	711	atomp
547	6758	nullp
564	46	null
576	18	lenp
587	6	len
599	371	assoc
643	96	pairlis
663	13	printval
702	301	readval
704	423	nonblank
714	122	readlist
770	9	readint
827	794	digit
835	973	letter
843	170	readident
867	301	readval
879	65	evcon
880	532	evlis
881	241	apply
882	3	letrec
884	711	eval
947	3	letrec
1012	65	evcon
1041	532	evlis
1061	10	membp
1071	6	memb
1083	1	isfinset
1093	195	applyprim
1198	241	apply
1239	28	dcprim
1261	1	readfname

Evaluation Completed

Statistics

System time was 633 milliseconds
User time was 24433 milliseconds

Module	Cells created
dcprim	84
cons	907
readiden	170
readint	9
letrec	18
null	46
len	6
equal	13
memb	6

Total cells 1259

Profile for overlay program

Berkel Pascal PXP -- Version 2.12 (5/11/83)

Wed Dec 12 12:48 1984 test11.p

Profiled Thu Dec 13 14:05 1984

Line	Count	func
1	1	
33	13	printval
36	1203	cellcount
62	13	equal
63	6758	nullp
84	14295	first
94	7556	rest

```

<<      3,      4>
, <      6,      5>
, <      8,      9>
, <      7,      2>
>

```

Evaluation Completed

Statistics

```

System time was      183 milliseconds
User time was        2333 milliseconds

```

```

-----
|Module      Cells created |
|-----|
|dcprim           84      |
|cons            907      |
|readiden        170      |
|readint           9      |
|letrec           18      |
|null            46      |
|len              6      |
|equal           13      |
|memb             6      |
|-----|
Total cells      1259

```

Results of overlay (Interpreted)

Enter Expression

```

<<      3,      4>
, <      6,      5>
, <      8,      9>
, <      7,      2>
>

```

```

        <call <var isfinfunc>
            <call <var rest>
                <var T>>>>>
    <con false>
                                                    >>>>
<letrec overlay
  <lambda <T pr>
    <if <<call <var equal>
      <call <var isfinfunc> <var T>>
      <con true>>
    <if <<call <var null> <var T>>
      <call <var cons> <var pr> <con <>>>
      <if <<call <var equal>
        <call <var first> <var pr>>
        <call <var first>
          <call <var first>
            <var T>>>>
        <call <var overlay>
          <call <var rest> <var T>>
          <var pr>>
        <call <var cons>
          <call <var first> <var T>>
          <call <var overlay>
            <call <var rest> <var T>>
            <var pr>>>
          >>>>
      <con Thotffunc>
                                                    >>>
    <call <var overlay>
      <call <var repr> <finset <3 4> <6 5> <8 9>>>
      <list 7 2> >>>>>!
```

Results of overlay function adding the value <3 4>
to the table. (Compiled)

Enter Expression

Overlay Function

Purpose

Overlay takes a finite function, (table), and returns an identical table with an additional pair added.

Practical Application

Overlay could be used as a way to update a database.

Source Code

```
<letrec firstlist
  <lambda <L>
    <if <<call <var null> <var L>>
      <con <>>
      <call <var cons>
        <call <var first>
          <call <var first> <var L>>>
        <call <var firstlist>
          <call <var rest>
            <var L>>>>>>>

<letrec isfinfunc
  <lambda <T>
    <if <<call <var null> <var T>>
      <con true>
      <if <<call <var equal>
        <call <var len>
          <call <var first> <var T>>>
        <con 2>>
      <if <<call <var memb>
        <call <var first>
          <call <var firstlist>
            <var T>>>
        <call <var rest>
          <call <var firstlist>
            <var T>>>>
      <con false>
```

1012	59	evcon
1041	738	evlis
1093	227	applyprim
1198	267	apply
1239	28	dcprim
1261	1	readfname

```
, < 79, 0.981627, 0.190809, 5.144554>
, < 80, 0.984808, 0.173648, 5.671282>
, < 81, 0.987688, 0.156434, 6.313752>
, < 82, 0.990268, 0.139173, 7.115370>
, < 83, 0.992546, 0.121869, 8.144346>
, < 84, 0.994522, 0.104528, 9.514364>
, < 85, 0.996195, 0.087156, 11.430052>
, < 86, 0.997564, 0.069756, 14.300666>
, < 87, 0.998630, 0.052336, 19.081137>
, < 88, 0.999391, 0.034899, 28.636253>
, < 89, 0.999848, 0.017452, 57.289962>
, < 90, 1.000000, 'undef', 'undef'>
>
```

Evaluation Completed

Statistics

```
System time was      4450 milliseconds
User time was        292650 milliseconds
```

```
-----
|Module           Cells created |
|-----|
|dcprim              34         |
|cons             10305         |
|readiden           121         |
|readint              3         |
|letrec              18         |
|eval               457         |
|GT                  92         |
|sum                 91         |
|null               547         |
|sinp                91         |
|cosp                91         |
|tanr                91         |
```

Total cells 11991

Results of trig table generator (Compiled)
Evaluation Completed

Statistics

System time was 1216 milliseconds
User time was 24100 milliseconds

Module Cells created
dcprim 84
cons 10305
readiden 121
readint 3
letrec 18
GT 92
sum 91
eval 457
null 547
tanr 91
cosp 91
sing 91

Total cells 11991

Profile for trigtable generating function
Berkeley Pascal PXP -- Version 2.12 (5/11/83)
Wed Dec 12 12:48 1984 test11.p
Profiled Thu Dec 13 09:36 1984

Line Count

1	1	func
33	456	printval
36	11935	cellcount
63	88505	nullp
84	189153	first
94	102572	rest
122	10305	cons
158	91	sum
330	92	GTP
340	92	GT
411	91	sinp
433	91	cosp
454	91	tann
539	10495	atomp
547	88505	nullp
564	547	null
599	5563	assoc
643	2284	pairlis
663	456	printval
702	211	readval
704	298	nonblank
714	87	readlist
770	3	readint
827	510	digit
835	634	letter
843	121	readident
867	211	readval
879	639	evcon
880	8118	evlis
881	3646	apply
882	3	letrec
884	10495	eval
947	3	letrec
1012	639	evcon

1041	8118	evlis
1093	2550	applyprim
1198	3646	apply
1239	28	dcprim
1261	1	readfname

Comparison of Programs Run With and Without the Memory Manager (MM)

General

The column labeled "left" in the following table refers to the number of cells that were in the freelist after evaluation of the program. This is caused by returning the cells that made the program list and is noteworthy because several programs could be loaded in the same file and evaluated without the danger of using all allocated memory.

Cells Created

<u>Program</u>	<u>MM</u>	<u>Nc MM</u>	<u>Left</u>	<u>System</u>	<u>User</u>
				<u>TIME</u>	<u>TIME</u>
Reverse	381	401	46	416	9566
Revaux	427	427	46	533	1090
Append	531	561	51	566	10583
Map(sine)	599	629	95	533	12233
Halving	774	898	102	816	15800
Collate	718	748	72	700	17566
Factorial	427	457	18	416	7566
Interval	1042	1192	211	933	34483
Filter	755	776	147	516	14233
Periodic	1071	1393	8	1116	53416
Split	611	670	24	466	12300

APPENDIX C

SOURCE CODE

```
(*Extended Lambda Calculus Interpreter*) program func(input, output);
type
  filename = packed array (1..80.) of char;
  tagtype = (lst, int, rea, alf, boo);
  list = @cell;
  (*Data structure for the cells of the program*)
  cell = record
    ref: integer;
    case tag: tagtype of
      lst: ( head, tail: list );
      int: ( ival: integer );
      rea: ( rval: real );
      alf: ( aval: alfa );
      boo: ( bval: boolean );
    end; (*Cell*)
  (*Data structure for free list*)
  freehdr = record
    numcells: integer;
    next: list;
  end;
  (*Data structure for tracking the number of cells created*)
```

```

cntinfo = record
    modul: alfa;
    cellcnt: integer;
end; (*cntinfo*)

(*There are 26 modules that create cells in the interpreter.
The array declared below is used to store information about
the number of cells each module creates*)
cntrec = array .)1..26.) of cntinfo;
var temp,primitives: list;
    ch: char;
    k,l: integer;
    infile: text;
    ans:char;
    callonly, diags,interac:boolean;
    dtmoyr, curtime: alfa;
    filearg: filename;
    newcells: integer;
    counts: cntrec;
    hdr: freehdr;

procedure printval(ls:list); forward;

(*****
* Function empty
*

```

```

* Purpose: Checks the free list to see if there are any cells available *
*
* to be retrieved.
*
*
* Calls: None
*
* Called by: sum, cons, subt, prod, divi, equal, LT, GT, GE, LE, sinp,
*
* cosp, tann, cot, sec, csc, atom, len, readrea, readint,
*
* readstring, readident, eval, letrec, memb
*****

```

```
function empty: boolean;
```

```
begin
```

```
    empty := hdr.next = nil;
```

```
end; (*Function empty*)

```

```

*****
* Function freecell
*
* Purpose: Retrieves cells from the freelist to be used where needed.
*
*
* Calls: None
*
* Called by: cons, sum, subt, prod, divi, equal, LT, GT, GE, LE, sinp,
*
* cosp, tann, cot, sec, csc, atom, null, len, readrea,
*
* readint, readstring, readident, eval, letrec, memb

```

```

*****
function freecell: list;
var C: list;
begin
    C := hdr.next;
    hdr.next := C@.tail;
    hdr.numcells := hdr.numcells - 1;
    freecell := C;
end; (*Function freecell*)

(*****
* Function return
*
* Purpose: Returns cells to the freelist when the cell's reference
*         count becomes zero.
*
* Calls: None
*
* Called by: decr
*****
procedure return(C: list);
begin
    if diags then begin
        writeln;
        writeln('*****');
    end;

```

```

writeln('*Examining the cell being returned');
writeln('* the tay for C is-----> ',C@.tay);
writeln('* printing the contents of C:');
    printval(C);
writeln;
writeln('*****');
end;
C@.tay := lst;
C@.ref := 0;
if empty then begin
    C@.tail := nil;
    hdr.next := C;
    hdr.numcells := hdr.numcells + 1;
end
else begin
    C@.tail := hdr.next;
    hdr.next := C;
    hdr.numcells := hdr.numcells + 1;
end;
writeln('In return number of cells in freelist is ',hdr.numcells);
end; (*Procedure return*)

(*****
* Function decr
*

```

```

* Purpose: Decrements the reference counts of cells that have references*
*          destroyed because of overwriting pointers or because they
*          become inaccessible.
*
*
* Calls: return
*
* Called by: ptrassn, initial, sub, equal, LT, assoc, pairlis,
*          readlist, eval, letrec, evcon, applyprim, apply
*****
procedure decr(C:list);
begin
  if C = nil then
    (*do nothing*)
  else if C@.ref = 0 then
    return(C)
  else begin
    C@.ref := C@.ref - 1;
    if C@.ref = 0 then begin
      if C@.tag = lst then begin
        decr(C@.head);
        decr(C@.tail);
        return(C);
      end
    else if (C@.tag = alf) | (C@.tag = int) |

```

```

        (C@.tag = rea) | (C@.tag = loo) then
            return(C)
        end
    end (*else begin*)
end; (*Procedure decr*)

(*****
* Function ptrassn
*
* Purpose: Automatically keeps track of the reference counts for two
*          pointers, one of which overwrites the other.
*
*
* Calls: decr
*
* Called by: last, initial, cons, consr, assoc, readlist, eval, letrec,
*            applyprim, apply
*****
procedure ptrassn (var x: list; y: list);
begin
    if diags then begin
        writeln('ref cnts of x and y in ptrassn if thy arent nil');
        if x <> nil then
            writeln(' x--> ', x@.ref);
        if y <> nil then
            writeln(' y--> ', y@.ref);
    end
end;

```

```

end;
if x <> nil then
  decr(x);
if y <> nil then
  y@.ref := y@.ref + 1;
x := y;
end; (*procedure ftrassn*)

(*****
* Function cellcount
*
* Purpose: Tabulates the number of cells created by the functions in the*
* interpreter.
*
* Calls: None
*
* Called by: cour, sum, subt, prod, divi, equal, LT, GT, GE, LE, sinp
*
*          cosp, tann, cot, sec, csc, atom, null, len, readrea,
*          readint, readstring, readident, eval, letrec, memb, dcprim
*****
procedure cellcount(i:integer; module:alfa);
var m: integer;
    quit: boolean;
begin
  m := 1;

```

```

quit := false;
newcells := newcells + i;
repeat
    if counts(.m.).modul = 'empty' then begin
        with counts(.m.) do begin
            modul := module;
            cellcnt := cellcnt + i;
        end;
        quit := true;
    end
else if counts(.m.).modul = module then begin
    counts(.m.).cellcnt := counts(.m.).cellcount + i;
    quit := true;
end;
m := m + 1;
if m = 27 then begin
    quit := true;
end;
until quit = true;
end; (*Procedure cellcount*)

function equal(x,y:list):list; forward; function nullp (L:list):boolean;
forward;

(*****

```

```

end
else
    P := freecell;
    with P do begin
        ref := 0;
        tag := int;
        ival := a@.ival * b@.ival;
    end;
    prod := P;
end
else if (a@.tag = rea) and (b@.tag = rea) then begin
    if empty then begin
        new(P, rea);
        cellcount(1, 'prod');
    end
end
else
    P := freecell;
    with P do begin
        ref := 0;
        tag := rea;
        rval := a@.rval * b@.rval;
    end;
    prod := P;
end

```

```

    rval := a@.rval - b@.rval;
    end;
    subt := S;
    enl
    else
        errormsg('subt', 3) (*Type mismatch*)
    end; (*Function subt*)
    (*****
    * Function prod
    *
    * Purpose: Multiplies two numbers, using the same technique previously
    *           described for sum.
    *
    *
    * Calls: empty, cellcount, freecell, errormsg
    *
    * Called by: applyprim
    *
    *****)
    function prod(a,b:list):list;
    var P:list;
    begin
        if (a@.tag = int) and (b@.tag = int) then begin
            if empty then begin
                new(P, int);
                cellcount(1, 'prod');
            end;
        end;
    end;

```

```

if (a@.tag = int) and (b@.tag = int) then begin
  if empty then begin
    new(S, int);
    cellcount(1, 'subt')
  end
else
  S := freecell;
  with S@ do begin
    ref := 0;
    tag := int;
    ival := a@.ival - b@.ival;
    end;
    subt := S;
    end (*if ... int*)
else if (a@.tag = rea) and (b@.tag = rea) then begin
  if empty then begin
    new(S, rea);
    cellcount(1, 'subt');
  end
else
  S := freecell;
  with S@ do begin
    ref := 0;
    tag := rea;

```

```

    R := freecell;
    with R@ do begin
        ref := 0;
        tag := read;
        R@.rval := a@.rval + b@.rval;
    end;
    sum := R;
end
else
    errormsg('sum', 3) (*Type mismatch*)
end; (*Function sum*)

```

```

(* **** *)
* Function subt
*
* Purpose: Subtracts two numbers. Subt always subtracts the second arg-
*          ument from the first.
*
* Calls: empty, cellcount, freecell, errormsg
*
* Called by: applyprim
* **** *)
function subt (a,b:list):list;
var S:list;
begin

```

```

*****
function sum(a,b: list): list;
  var R,I: list;
  begin
    if (a@.tag = int) and( b@.tag = int) then begin
      if empty then begin
        new(I, int);
        cellcount(1, 'sum');
      end
    else
      I := freecell;
      with I@ do begin
        ref := 0;
        tag :=int;
        I@.ival := a@.ival + b@.ival;
      end;
      sum := I;
    end
  else if (a@.tag = rea) and( b@.tag = rea) then begin
    if empty then begin
      new(R, rea);
      cellcount(1, 'sum');
    end
  else

```

```

head:= T;
writeln('In conr 23');
tail:= nil;
end;

p@.tail:= C;
C@.ref := C@.ref + 1;
conr := H;
end;

(*decr(P);
decr(C);*)

end; (*Function conr*)

```

```

*****
* Function sum
*
* Purpose: Adds two integers or real numbers, found in the variant
*          fields of the arguments delivered to the function. The re-
*          sult is returned through a pointer to another cell, created
*          created in the function.
*
*
* Calls: cellcount, freecell, errormsy
*
* Called by: applyprim
*****

```

```

*****
function cons(H, T: list): list;
var P,C: list;
begin
    if H <> nil then
        H@.ref := H@.ref + 1;
    if T <> nil then
        T@.ref := T@.ref + 1;
    if nullp(H) then
        cons := cons(T, nil)
    else begin
        writeln('In cons 1st call');
        ptrassn(P, H);
        while P@.tail <> nil do
            P := P@.tail;
        if empty then begin
            new(C,1st);
            cellcount(1, 'cons');
        end
    else
        C := freecell;
        with C@ do begin
            ref := 0;
            tag := 1st;

```

```

C:= freecell;
with C@ do begin
    ref := 0;
    tag := lst;
    head := nil;
    tail := nil;
    ptrassn(head, H);
    ptrassn(tail, T);
end;

cons := C;
end; (*Function cons*)

(*****
* Function consr
*
* Purpose: Same idea as cons except the first argument is made the last
* element of the second argument (list). Notice that the
* technique is different than that used in cons. Since lists
* are accessed by pointers to their first elements, the list
* tree must be walked down to the last element before the
* first argument can be added to the end of the list
*
*
* Calls: ptrassn, cellcount, cons, nullp
*
* Called by: applyprim
*)

```

```

decr(L);
decr(O);
decr(P);

end; (*Function initial*)

(*****
* Function cons
*
* Purpose: Receives two arguments: the first being an atom or list and
*         and the second which must be a list. Cons takes the first
*         argument and makes it the first element of the second argu-
*         ment (which is a list).
*
* Calls: ptrassn
*
* Called by: conr, pairlis, eval, letrec, evlis, applyprim, dcprim
*****
function cons(H,T: list): list;
var C: list;
begin
    if empty then begin
        new( C, lst);
        cellcount(1, 'cons');
    end
    else

```

```

*
* Purpose: Receives a list as an argument and returns all elements of
*          that list except the last element.
*
*
* Calls: ptrassn, decr, errormsg
*
* Called by: applyprim
*****
function initial (L:list): list;
  var O,P: list;
  begin
    if L = nil then
      errormsg('initial', 1)
    else if L@.tag = lst then begin
      ptrassn(P, L);
      repeat
        ptrassn(O, P);
        ptrassn(P, P@.tail);
      until P@.tail = nil;
      O@.tail := nil;
      initial := L
      end
    else
      errormsg('initial', 2);
    end
  end
*****

```

```

end; (*Function first*)

(*****
* Function rest
*
* Purpose: Receives a list as an argument and returns all elements
*           of that list except the first element
*
* Calls: errormsg
*
* Called by: sub, lenp, assic, pairlis, printval, eval, evcon, membp,
*           applyprim, apply
*****
function rest (L: list): list;
begin
    if L = nil then
        errormsg('rest', 1)
    else if L@.tay = lst then
        rest := L@.tail
    else
        errormsg('rest', 2);
    end; (*Function rest*)
)

(*****
* Function initial
*
```

```

        last := L@.head
      end
    else
      errormsy('last', 2);
    end; (*Function last*)

    (*****
    * Function first
    *
    * Purpose: Receives a list as an argument and returns the first element
    *           of that list.
    *
    * Calls: None
    *
    * Called by: sub, equalp, assoc, pairlis, printval, eval, evcon, membp,
    *            isfinset, applyprim, apply
    *
    *****)
    function first (L:list): list;
    begin
      if L = nil then
        errormsy('first', 1)
      else if L@.tag = lst then
        first := L@.head
      else
        errormsy('first', 2);

```

```

9: writeln(' Cell for condition is not 'boo');
10: writeln(' First element of the list must be an 'alf' cell');
11: writeln(' Attribute to be looked up must be in an 'alf' cell');
12: writeln(' Attempted to take 'repr' of non finset');
    end; (*case msgy of*)
    end; (*Procedure errormsg*)

```

```

(*****
* Function last
*
* Purpose: Receives a list as an argument and returns the last element
*           of that list.
*
* Calls: ptrassn
*
* Called by: applyprim
*****
function last (L:list): list;
begin
    if L = nil then
        errormsg('last', 1)
    else if L@.tag = lst then begin
        repeat
            ptrassn(L, L@.tail);
        until L@.tail = nil;
    end;
end;
)

```

```

* Function errormsg
*
* Purpose: Informs the user when errors occur while using the
* interpreter. Each error message is annotated to tell where
* it was called from.
*
* Calls: None
*
* Called by: initial, sum, sub, prod, divi, sub, LT, GT, GE, LE, sinp,
* COSP, TANN, COT, SEC, CSC, ASSOC, EVAL EVCON, ISFINSET,
* applyprim
*****
procedure errormsg(module: alfa; msg: integer);
begin
    writeln( 'There is an error in module--> ', module);
    case msg of
        1: writeln(' Cell sent to function is nil');
        2: writeln(' Cell sent to function is not a '1st' cell');
        3: writeln(' Types of arguments sent to binary function clash');
        4: writeln(' Index to sub is 0 or not an integer');
        5: writeln(' Cell sent to function must be 'rea' or 'int');
        6: writeln(' Value not found in current environment for:');
        7: writeln(' Key word below not recognized by eval');
        8: writeln(' Condition evaluated to nil');
    end case;
end;
*****

```

```

else
    errormsy('prod', 3) (*Type clash*)
end; (*Function prod*)

(*****
 * Function divi
 *
 * Purpose: Divides two numbers
 *
 * Calls: empty, cellcount, freecell, errormsy
 *
 * Called by: applyprim
 *****)
function divi(a, b:list):list;
    var D:list;
    begin
        if (a@.tag = int) and (b@.tag = int) then begin
            if empty then begin
                new(D, int);
                cellcount(1, 'divi');
            end
        else
            D := freecell;
            with D@ do begin
                ref := 0;

```

```

    tag := int;
    ival := a@.ival div b@.ival;
end;

divi := D;
end (*if (a@...*)
else if (a@.tag = rea) and (b@.tag = rea) then begin
    if empty then begin
        new(D, rea);
        cellcount(1, 'divi');
    end
    else
        D := freecell;
        with D@ do begin
            ref := 0;
            tag := rea;
            rval := a@.rval / b@.rval;
        end;
        divi := D;
        end (*else if*)
    else
        errormsy('divi', 3)
    end; (*Function divi*)
    (*****
    * Function sub
    *

```

```

*
* Purpose: Receives a list and an integer as arguments. Returns the
* element of the list corresponding to the integer, e.g., if
* the integer is 2, the second element of the list is returned.*
*
* Calls: errmsg, rest, first, decr
*
* Called by: applyprim
*****
function sub(L,i:list):list;
  var count: integer;
  begin
    i@.ref := i@.ref + 1;
    if (i@.tag <> int) or (i@.ival = 0) then
      errmsg('sub', 4)
    else begin
      count := i@.ival;
      (*Decrease the size of the list by one until the desired element is
      the first element of a sublist, and return that element*)
      while count <> 1 do begin
        L := rest(L);
        count := count - 1;
      end;
    end;
  end;
*****

```

```

sub := first(L);
writeLn('EEEEEEEEEEEEEEEEleaving sub');
end; (*Function sub*)

(*****
 * Function equalp
 *
 * Purpose: Works in tandem with the equal function. Equalp tests for
 * the equality of the arguments sent to it by equalp. The
 * arguments can be identifiers, numbers, or lists.
 *
 * Calls: rest, first, nullp
 *
 * Called by: equal, membp
 *****)
function equalp(x,y:list):boolean;
begin
  if (nullp(x)) and (nullp(y)) then
    equalp := true
  else if (x@.tag = alf) and (y@.tag = aif) then
    equalp := x@.aval = y@.aval
  else if (x@.tag = int) and (y@.tag = int) then
    equalp := x@.ival = y@.ival
  else if (x@.tag = rea) and (y@.tag = rea) then
    equalp := x@.rval = y@.rval

```

```

else if (x@.tag = lst) and (y@.tag = lst) then begin
    if equalp(first(x), first(y)) then
        equalp := equalp(rest(x), rest(y))
    end
else
    equalp := false
end; (*Function equalp*)

(*****
* Function equal
*
* Purpose: Creates a cell to hold the Boolean response of function
*          equalp.
*
* Calls: empty, cellcount, freecell, equalp, decr
*
* Called by: applyprim
*****
function equal;
var E:list;
begin
    x@.ref := x@.ref + 1;
    y@.ref := y@.ref + 1;
    if empty then begin
        new( E,boo);
    end
end;
)

```

```

        cellcount(1, 'equal');
    end
else
    E := freecell;
    with E do begin
        ref := 0;
        tag := boo;
        lval := equalp(x,y)
    end;
    equal := E;
    decr(x);
    decr(y);
end; (*Function equal*)

```

```

(*****
* Function LTp (Less Than)
*
* Purpose: Same idea as the equal function except the first argument
*           argument is tested to see if it is less than the second.
*
* Calls: errormsg
*
* Called by:
*****
function LTp(x,y:list):boolean;

```

```

begin
  if (x@.tag = int) and (y@.tag = int) then
    LTP := x@.ival < y@.ival
  else if (x@.tag = rea) and (y@.tag = rea) then
    LTP := x@.rval < y@.rval
  end; (*Function LTP*)

  (*****
   * Function LT (Less Than)
   * Purpose: Creates a cell the hold the Boolean response of calls to
   *           LTP.
   * Calls: empty, cellcount, freecell, errormsg, decr
   *
   * Called by: applyprim
   *****)
function LT(x,y:list):list;
var A:list;
begin
  x@.ref := x@.ref + 1;
  y@.ref := y@.ref + 1;
  if ((x@.tag = int) and (y@.tag = int)) |
    ((x@.tag = rea) and (y@.tag = rea)) then begin
    if empty then begin
      new( A,boo);
      cellcount(1, 'LT');

```

```

end
else
    A := freecell;
    with A@ do begin
        ref := 0;
        tay := boo;
        bval := LTP(x,y)
    end;
    LT := A
end
else
    errormsg('LT', 3);
    decr(x);
    decr(y);
    end; (*Function LT*)
(
*****
* Function GTP (Greater Than)
*
* Purpose: Determines if argument one is greater than argument two.
*
* Calls: errormsg
*
* Called by:
*****
)

```

```

function GTP(x,y:list): boolean;
begin
    if (x@.tag = int) and (y@.tag = int) then
        GTP := x@.ival > y@.ival
    else if (x@.tag = rea) and (y@.tag = rea) then
        GTP := x@.ival > y@.ival
    end; (*Function GTP*)
end;

(*****
* Function GT (Greater Than)
*
* Purpose: Creates a cell for the Boolean responses of calls to func-
*         tion GTP.
*
* Calls: empty, cellcount, freecell, errormsg
*
* Called by: applyprim
*****
function GT(x,y:list):list;
var A:list;
begin
    if ((x@.tag = int) and (y@.tag = int)) |
        ((x@.tag = rea) and (y@.tag = rea)) then begin
        if empty then begin
            new( A, boo);

```

```

cellcount(1, 'GT');
end
else
  A := freecell;
  with A do begin
    ref := 0;
    tay := too;
    bval := GTP(x, y)
  end;
  GT := A
end (*if*)
else
  errormsg('GT', 3)
end; (*Function GT*)

(*****
* Function GEP
*
* Purpose: Determines if argument 1 is greater than or equal to argu-
*          ment 2.
*
* Calls: errormsg
*
* Called by:
*****)

```

```

function GEp(x,y:list): boolean;
begin
    if (x@.tag = int) and (y@.tag = int) then
        GEp := x@.ival >= y@.ival
    else if (x@.tag = rea) and (y@.tag = rea) then
        GEp := x@.rval >= y@.rval
    end; (*Function GEp*)
(*****
* Function GE
*
* Purpose: Creates a cell to hold Boolean responses from call to func-
*         tion GEp.
*
* Calls: empty, cellcount, freecell, errormsj
*
* Called by: applyprim
*****
function GE(x,y:list):list;
var A:list;
begin
    if ((x@.tag = int) and (y@.tag = int)) |
        ((x@.tag = rea) and (y@.tag = rea)) then begin
        if empty then begin
            new(A, too);

```

```

        ceilcount(1, 'GE');
    end
else
    A := freecell;
    with A@ do begin
        ref := 0;
        tay := too;
        lval := GEP(x,y)
    end;
    GE := A
end
else
    errormsg('GE', 3)
end; (*Function GE*)

(*****
* Function LEp
*
* Purpose: Determines whether argument 1 is less than or equal to argu-
*          ment 2
*
* Calls: errormsg
*
* Called by:
*****)

```

```

function LEp(x,y:list): boolean;
begin
    if (x@.tag = int) and (y@.tag = int) then
        LEp := x@.ival <= y@.ival
    else if (x@.tag = rea) and (y@.tag = rea) then
        LEp := x@.rval <= y@.rval
    end; (*Function LEp*)
end;

(******
* Function LE
*
* Purpose: Creates a cell to hold Boolean responses from calls to func-
*         tion LEp.
*
* Calls: empty, cellcount, freecell, errormsg
*
* Called by: applyprim
******)
function LE(x,y:list):list;
var A:list;
begin
    if ((x@.tag = int) and (y@.tag = int)) |
        ((x@.tag = rea) and (y@.tag = rea)) then begin
        if empty then begin
            new(A, too);

```

```

        cellcount(1, 'LE');
    end
else
    A := freecell;
    with A@ do begin
        ref := 0;
        tag := 100;
        bval := LEp(x,y)
    end;
    LE := A
end
else
    errormsg('LE', 3)
end; (*Function LE*)

(*****
* Function sinp
*
* Purpose: Determines the sin of a an angle in degrees.
*
* Callis: empty, cellcount, freecell, errormsg
*
* Called by: applyprim
*****)
function sinp(x:list):list;

```

AD-A155 218

A PASCAL INTERPRETER FOR THE FUNCTIONAL PROGRAMMING
LANGUAGE ELC (EXTENDED LAMBDA CALCULUS)(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA R P STEEN DEC 84

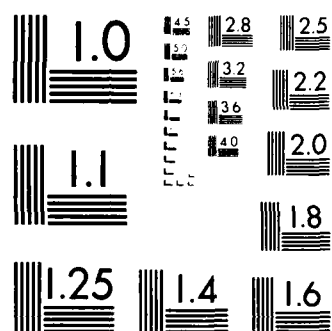
3/3

UNCLASSIFIED

F/G 9/2

NL

									END			



MICROCOPY RESOLUTION TEST CHART
NA 109A: 1963-A

```

var A:list;
    rad:real;
begin
    if (x@.tag = int) or (x@.tag = rea) then begin
        (*Convert degrees to radians to use built in trig functions*)
        case x@.tag of
            int: rad := (x@.ival * 3.141592654)/180.0;
            rea: rad := (x@.rval * 3.141592654)/180.0;
        end; (*case x@.tag*)
        if empty then begin
            new(A, rea);
            cellcount(1, 'sinf');
        end
    else
        A := freecell;
        with A@ do begin
            ref := 0;
            tag := rea;
            rval := sin(rad);
        end;
        sinp := A;
        end (*if (x@.tag...*)
    else
        errormsg('sinp', 5) (*Can only take the sin of a real or integer*)

```

```

end; (*Function sinp*)

(*****
* Function cosp
*
* Purpose: Determines the cosine of an angle given in degrees.
*
* Calls: empty, cellcount, freecell, errormsg
*
* Called by: applyprim
*****
function cosp(x:list):list;
  var A:list;
      rad:real;
begin
  if (x@.tag = int) or (x@.tag = rea) then begin
    case x@.tag of
      int: rad := (x@.ival * 3.141592654)/180.0;
      rea: rad := (x@.rval * 3.141592654)/180.0;
    end; (*case x@.tag*)
    if empty then begin
      new(A, rea);
      cellcount(1, 'cosf');
    end
  else

```

```

    A := freecell;
    with A@ do begin
        ref := 0;
        tay := rea;
        rval:= cos(rad);
        end;
        cosp:= A;
        end (*if (x@.tag...*)
    else
        errormsg('cosp', 5) (*Can only take the cos of a real or integer*)
    end; (*Function cosp*)

    (*****
    * Function tann (Tangent)
    *
    * Purpose: Determines the tangent of an angle, given in degrees.
    *
    * Calls: empty, cellcount, freecell, errormsg
    *
    * Called by: applyprim
    *****
    function tann(x:list):list;
        var A:list;
            rad:real;
        begin

```

```

if (x@.tag = int) or (x@.tag = rea) then begin
    (*Convert degrees to radians*)
    case x@.tag of
        int: rad := (x@.ival * 3.141592654) / 180.0;
        rea: rad := (x@.rval * 3.141592654) / 180.0;
    end; (*case x@.tag*)
    if empty then begin
        new(A, rea);
        cellcount(1, 'tanr');
    end
    else
        A := freecell;
        with A@ do begin
            ref := 0;
            tag := rea;
            rval := sin(rad) / ccs(rad);
            end;
            tann := A;
            end (*if (x@.tag...*)
        else
            errormsg('tann', 5) (*Can only take the tan of a real or integer*)
            end; (*Function tanr*)
    (*****
    * Function cot (cotangent)
    *

```

```

*
* Purpose: Determines the cotangent of an angle given in degrees.
*
*
* Calls: empty, cellcount, freecell, errormsg
*
* Called by: applyprim
*****
function cot(x:list):list;
  var A:list;
      rad:real;
begin
  if (x@.tag = int) or (x@.tag = rea) then begin
    case x@.tag of
      int: rad := (x@.ival * 3.141592654)/180.0;
      rea: rad := (x@.rval * 3.141592654)/180.0;
    end; (*case x@.tag*)
    if empty then begin
      new(A, rea);
      cellcount(1, 'cot');
    end
  else
    A := freecell;
    with A@ do begin
      ref := 0;

```

```

tag := rea;
rval:= 1/(sin(rad)/cos(rad));
end;

cot:= A;
end (*if (x@.tag...*)
else
    errmsg('cot', 5) (*Can only take the cot of a real or integer*)
end; (*Function cot*)
(*****
* Function sec (Secant)
*
* Purpose: Determines the secant of an angle given in degrees.
*
* Calls: empty, cellcount, freecell, errormsy
*
* Called by: applyprim
*****
function sec(x:list):list;
    var A:list;
        rad:real;
begin
    if (x@.tag = int) or (x@.tag = rea) then begin
        case x@.tag of
            int: rad := (x@.ival * 3.141592654)/180.0;

```

```

rea: rad := (x@.rval * 3.141592654) / 180.0;
end; (*case x@.tag*)
if empty then begin
  new(A, rea);
  cellcount(1, 'sec');
end
else
  A := freecell;
  with A@ do begin
    ref := 0;
    tag := rea;
    rval := 1/cos(rad);
  end;
  sec := A;
end (*if (x@.tag...*)
else
  errormsg('sec', 5) (*Can only take the sec of a real or integer*)
end; (*Function sec*)

(*****
* Function csc (Cosecant)
*
* Purpose: Determines the cosecant of an angle given in degrees.
*
* Calls: empty, cellcount, freecell, errormsg
*)

```

```

*
* Called by: applyprim
*
*****
function csc(x:list):list;
  var A:list;
      rad:real;
begin
  if (x@.tag = int) or (x@.tag = rea) then begin
    case x@.tag of
      int: rad := (x@.ival * 3.141592654)/180.0;
      rea: rad := (x@.rval * 3.141592654)/180.0;
    end; (*case x@.tag*)
    if empty then begin
      new(A, rea);
      cellcount(1, 'csc');
    end
  else
    A := freecell;
    with A@ do begin
      ref := 0;
      tag := rea;
      rval := 1/sin(rad);
    end;
    csc := A;
  end;
end;
*****

```

```

        end (*if (x@.tag...*)
    else
        errmsg('csc', 5) (*Can only take the csc of a real or integer*)
    end; (*Function csc*)

    (*****
    * Function atomp
    *
    * Purpose: Determines whether the argument sent to it is an atom.
    *
    * Calls: None
    *
    * Called by: atom, eval
    *
    *****)
    function atomp (L:list): boolean;
    begin
        if L=nil then
            atomp := false
        else
            atomp := L@.tag<>lst;
        end; (*Function atomp*)
    (*****
    * Function nullp
    *
    *)

```

```

* Purpose: Must receive a list as an argument. Nullp determines if the *
* list is null (empty). *
* *
* Calls: None *
* *
* Called by: conr, null, lenr, assoc, pairlis, evlis, membp *
*****
function nullp;
begin
    nullp := L=nil;
end; (*Function nullp*)

(*****
* Function atom *
* *
* Purpose: Creates a cell to hold the Boolean responses from calls to *
* function atomp. *
* *
* Calls: empty, cellcount, freecell, atomp *
* *
* Called by: applyprim *
*****
function atom (L:list): list;
var B: list;
begin

```

```

if empty then begin
    new (B, loc);
    cellcount(1, 'atom');
end
else B := freecell;
with B do begin
    ref := 0;
    tag := boc;
    bval := atomp(L)
end;

atom := B;
end; (*Function atom*)

(*****
* Function null
*
* Purpose: Creates a cell to hold the response from a call to function
*          nullp.
*
* Calls: emptyl cellcount, freecell, nullp
*
* Called by: applyprim
*****
function null (L: list): list;
var B: list;

```

```

begin
  if empty then begin
    new( B, boo);
    cellcount(1, 'null');
  end
else
  B := freecell;
  with B@ do begin
    ref := 0;
    tag := boo;
    lval := nullp(L)
  end;
  null := B;
end; (*Function null*)

(*****
* Function lenp
*
* Purpose: Determines the length of a list by recursively counting the
*          number of elements.
*
* Calls: nullp, lenp, rest
*
* Called by: len
*****)

```

```

*
* Called by: readval
*
*****
function readint: list;
  var n: integer;
      I: list;
begin
  n := 0;
  repeat
    n := n*10 + ord(ch) - ord('0');
  if interac then
    read(ch)
  else
    read(infile,ch);
  until (ch<'0') or ('9'<ch) or (ch='.'');
  if ch = '.' then
    readint := readrea(n)
  else begin
    if empty then begin
      new( I, int);
      cellcount(1, 'readint');
    end
  else
    I := freecell;

```

```

        read(ch)
    else
        read(infile,ch);
    end; (*while (ch*)
    if empty then begin
        new(R,rea);
        cellcount(1, 'readrea');
    end
    else
        R := freecell;
        with R@ do begin
            ref := 0;
            tag := rea;
            rval := k;
        end;
        readrea := R;
    end; (*Function readrea*)
    (*****
    * Function readint (Read Integer)
    *
    * Purpose: Places integers in the proper cells, 'int', as programs are
    *           being read, initially.
    *
    * Calls: readrea, empty, cellcount, freecell
    *
    *
    *
    *
    *)

```

```

*
* Purpose: Places real numbers in the proper cell as the program is
*          being read.
*
*
* Calls: empty, cellcount, freecell
*
* Called by: readint
*****
function readrea(i:integer): list;
var R:list;
    k:real;
    n,expo:integer;
begin
    k:= 0.0;
    expo:=1;
    if interac then
        read(ch)
    else
        read(infile,ch);
    while (ch >= '0') and (ch <= '9') do begin
        n:= n*10 + ord(ch) - ord('0');
        k:= i + (n * (1/(exp(expo * ln(10)))));
        expo := expo +1;
        if interac then

```

```

    read(ch)
else
    read(infile,ch);
nonblank;
if ch = '>' then
    readlist := nil
else begin
    L:= cons( readval, nil );
    readlist := L;
    nonblank;
    while ch <> '>' do begin
        ptrassn(C, cons( readval, nil));
        ptrassn(L@.tail, C);
        L:= C;
        nonblank;
    end;
end;
if interac then
    read(ch)
else
    read(infile,ch);
end; (*Function readlist*)
(*****
* Function readrea (Readreal)

```

```

procedure nonblank;
begin
    while ch = ' ' do begin
        if interac then
            read(ch)
        else
            read(infile,ch)
        end
    end; (*Procedure nonblank*)
(*****
* Function readlist
*
* Purpose: At this point a left bracket has been recognized, so the next
* characters are part of a list. Readlist builds all lists
* and terminates when a right bracket is recognized.
*
* Calls: nonblank, ptrassn, readval, decr
*
* Called by: readval
*****
function readlist: list;
var L, C: list;
begin
    if interac then

```

```

i := 1;
while not(ls@.aval(.i.) = ' ') do begin
    write(ls@.aval(.i.));
    i := i+1;
end;
end;
boo: begin
    if diags then
        write(' /tag is boo, ref = ',ls@.ref:1,' /');
        write(ls@.bval);
    end
end;
end;
end; (*Procedure printval*)

function readval: list; forward;

```

```

(*****
* Function nonblank
*
* Purpose: Passes by blanks when reading input either from a terminal
*          or a file until the next character is read.
* Calls:
*
* Called by: readlist
*****)

```

```

Printval(first(L));
L:= rest(L);
if L <> nil then begin
    write(' ');
    if diags then
        writeln;
    end
until L = nil;
write('>');
writeln;
end;
int: begin
    if diags then
        write(' /tag is int,ref = ',ls@.ref:1,' /');
        write(ls@.ival:6);
    end;
rea: begin
    if diags then
        write(' /tag is rea,ref = ',ls@.ref:1,' /');
        write(ls@.rval:6:6);
    end;
alf: begin
    if diags then
        write(' /tag is alf, ref= ',ls@.ref:1,' /');

```

```

*      tail of the 'lst' cells until the atom cells are found.      *
*      When an atom cell is found, the contents of it are immediate--*
*      ly printed out.      *
*      *      *      *      *      *      *      *      *      *      *
*      Calls: first, rest      *
*      *      *      *      *      *      *      *      *      *      *
*      Called by: main program      *
*****
procedure printval;
var l: list;
    i: integer;
begin
    if ls = nil then
        write('<>')
    else
        case ls@.tag of
            lst: begin
                l:= ls;
                write('<');
                if diags then begin
                    write(' /tag is lst,ref= ',ls@.ref:1,' /');
                    writeln;
                end;
                repeat

```

```

writeln;
writeln('IN function pairlis we are linking');
writeln(' v is below');
printval(v);
writeln;
writeln(' DO you want to try to read x? y/n');
readln(ans);
if ans = 'y' then
    printval(x);
end; (*if diags*)
if nullp(v) then
    pairlis := A
else
    pairlis:= cons( cons( first(v), cons( first(x), nil)),
        pairlis( rest(v), rest(x), A));
    decr(v);
    decr(x);
    decr(A);
end; (*Function pairlis*)
(*****
* Procedure printval
*
* Purpose: Prints the contents of any list by starting at the top of the
*          list tree and recursively calling itself on the head and tail*
*****

```

```

    decr(t);
end; (*Function assoc*)

(*****
* Function pairlis
*
* Purpose: Given a list of bound variable, v, and a list of actual
* values, x, pairlis binds the variables with the actuals by
* creating lists of pairs (attribute value pairs). These
* lists of pairs are then added to the current environment, A,
* for use in the evaluation of a function call.
*
* Calls: nullp, cons, first, decr, rest
*
* Called by: eval, apply
*****
function pairlis (v, x, A: list) :list;
begin
    if v <> nil then
        v@.ref := v@.ref + 1;
    if x <> nil then
        x@.ref := x@.ref + 1;
    if A <> nil then
        A@.ref := A@.ref + 1;
    if diags then begin

```

```

if diags then begin
  (*Print out trace information*)
  writeln;
  writeln('IN function assoc, looking for the value for ');
  printval(x);
  writeln;
  writeln('DO you want to try to see what was found? y/n');
  writeln('if x is a recursive function;it can't be printed'.);
  readln(ans);
  if ans = 'y' then
    printval( first(rest(first(r)))));
  writeln;
  end; (*if diags*)
  assoc := first(rest(first(r)));
  end (*if found*)
else begin
  errormsg('assoc', 6);
  printval(x);
  writeln;
  end
end;

decr(A);
decr(x);
decr(r);

```

```

r, t: list;
found: boolean;
begin
  if A <> nil then
    A@.ref := A@.ref + 1;
  if x <> nil then
    x@.ref := x@.ref + 1;
  if nullp(x) then
    errormsg('assoc', 1)
  else if x@.tag<>alf then
    errormsg('assoc', 11)
  else begin
    v:= x@.aval;
    ptrassn(r, A);
    found := false;
    while not nullp(r) and not found do begin
      ptrassn(t, first(first(r)) );
      u := t@.aval;
      if u=v then found := true
      else begin
        ptrassn(r, rest(r) );
      end
    end; (*while not*)
    if found then begin

```

```

    cellcount(1, 'len');
  end
else
  A := freecell;
  with A@ do begin
    ref := 0;
    tag := int;
    ival := lenp(L)
  end;
  len := A;
end; (*Function len*)

```

```

(*****
* Function assoc
*
* Purpose: Given an association list, 'A', and an attribute, x, find
*           the value for x, e.g., for A = <x, 'value'>, 'value' would
*           be returned.
*
* Calls: nullp, errormsy, ptrassn, first, rest, decr
*
* Called by:
*****
function assoc (A,x: list): list;
  var u, v: alfa;
)

```

```

function lenp(L:list):integer;
  var length:integer;
  begin
    length := 0;
    if nullp(L) then
      length := 0
    else
      length := 1 + (lenp(rest(L)));
      lenp := length
    end; (*Function lenp*)
  (*****
   * Function len
   *
   * Purpose: Creates a 'int' cell to hold the result of a call to lenp.
   *
   * Calls: empty, cellcount, freecell, lenp
   *
   * Called by: applyfrim
   *****)
function len(L:list):list;
  var A:list;
  begin
    if empty then begin
      new(A, int);

```

```

with I@ do begin
    ref := 0;
    tag := int;
    ival := n
end;
readint := I;
end(*else begin*)
end; (*Function readint*)

```

```

(******
* Function readstring
*
* Purpose: Reads quoted strings and places them in the proper cells
*          ('alf'), as the program is read.
*
* Calls: cellcount, freecell
*
* Called by: readval
*****
function readstring: list;
var a: alfa;
    i: integer;
    A: list;
begin
    if interac then

```

```

    read(ch)
else
    read(infile,ch);
    i := 1;
    a:= ' ';
    while ch <> '' do begin
        a(.i.) := ch;
        i := i+1;
        if interac then
            read(ch)
        else
            read(infile,ch)
        end;
        if empty then begin
            new( A, alf);
            cellcount(1, 'readstr');
            end
        else
            A := freecell;
            with A@ do begin
                ref := 0;
                tag := alf;
                aval := a
            end;

```

```

    if interact then
        read(ch)
    else
        read(infile,ch);
        readstring := A;
    end; (*Function readstring*)
    (*****
    * Function digit
    *
    * Purpose: Boolean function to recognize digits.
    *
    * Calls: None
    *
    * Called by: readident
    *
    *****)
    function digit(ch: char):boolean;
    type digits = set of char;
    var digitset : digits;
    begin
        digitset := ('0'..'9'.);
        digit := ch in digitset;
    end; (*Function digit*)
    (*****

```

```

* Function letter
*
* Purpose: Boolean function to recognize upper and lower case letters
*
*
* Calls:
*
* Called by: readident
*****
function letter(ch: char): boolean;
type letters = set of char;
var letterset : letters;
begin
    letterset]:= ('a'..'z','A'..'Z'.);
    letter := ch in letterset;
end; (*Function letter*)
(*****
* Function readident
*
* Purpose: Places identifiers (up to 10 letters, characters or combina-
*         tion), in the proper cell as a program is being read.
*
*
* Calls: cellcount, freecell, empty
*
* Called by: readval

```

```

*****
function readident: list;
var a: alfa;
    i: integer;
    A: list;
begin
    i := 1;
    a := ' ';
    while letter(ch) | digit(ch) do begin
        a(.i.) := ch;
        i:=i+1;
        if interac then
            read(ch)
        else
            read(infile,ch);
        end; (*while ch*)
        if empty then begin
            new(A, alf);
            cellcount(1, 'readiden');
        end
    else
        A := freecell;
        with A@ do begin
            ref := 0;

```

```

    tay := alf;
    aval := a;
    end;

    readident := A;
end; (*Function readident*)

(*****
* Function readval
*
* Purpose: Readval is the first function called, as a program is read.
* Readval recognized the first letter of the program and deter-
* mines if a list, integer, real, or identifier is being read.
*
* Calls: readlist, readstring, readident, readint
*
* Called by: readlist, main program
*****
function readval;
begin
    if ch = '<' then
        readval := readlist
    else if ch = ''' then
        readval := readstring
    else if letter(ch) then
        readval := readident

```

```

else
    readval := readint
    end; (*Function readval*)

function evcon (L,a: list): list; forward;
function evlis (L,a: list): list; forward;
function apply (f,x: list): list; forward;
function letrec(f, lam, bdy, a: list): list; forward;

(*****
* Function eval
*
* Purpose: Main decoding function of the interpreter. Strips the first
*           element from the expression and determines how the expression
*           is to be evaluated.
*
* Calls: atomp, ptrassn, first, rest, assoc, letrec, cons, empty
*         cellcount, freecell, apply, evlis, eval, evcol, pairlis, decr,
*         errormsg
*
* Called by: eval, letrec, evlis
*****
function eval (e, a: list): list;
    var T,C,elp: list;
        el:alfa;

```

```

begin
  if diags then begin
    (*Print out trace information*)
    writeln;
    writeln('IN function eval, the expression being evaluated is: ');
    printval(e);
    writeln;
  end;
  (*writeln('Entering eval the ref cnt to e is ',e@.ref);
  writeln('      '
          a is ',a@.ref);*)
  if e <> nil then
    e@.ref := e@.ref + 1;
  if a <> nil then
    a@.ref := a@.ref + 1;
  if atomp(e) then eval := e
  else begin
    ptrassn(e1p, first(e));
    e1 := e1p@.aval;
    if e1 = 'list' then eval := evlis(rest(e), a)
    else if e1 = 'finset' then eval := e
    else if e1 = 'con' then eval := first( rest(e))
    else if e1 = 'var' then eval := assoc( a, first( rest(e)))
    else if e1 = 'letrec' then eval := letrec(first( rest(e)),
      first(rest(rest(e))), first(rest(rest(e))), a)

```

```

else if e1 = 'lambda' then begin
  if empty then begin
    new(C, alf);
    cellcount(1, 'eval');
  end
else
  C := freecell;
  with C@ do begin
    ref := 0;
    tag := alf;
    aval := 'closure';
  end;
  eval := cons( cons(C,e), cons(a,nil) );
  end (*if e1 = 'lambda'*)
else if e1 = 'if' then eval := evcon( rest(e), a)
else if e1 = 'call' then
  eval := apply(eval( first(rest(e)), a), evlis( rest(rest(e)), a))
else if e1 = 'apply' then
  eval := apply(eval(first(rest(e)),a),eval(first(rest(rest(e))),a))
else if e1 = 'let' then begin
  (*if diags then begin
    writeln('rest(e)');
    printval(rest(e));
    writeln;

```

```

writeln('first(rest(e))');
printval(first(rest(e)));
writeln;
writeln('first(rest(first(rest(e))))');
printval(first(rest(first(rest(e)))));
writeln;
writeln('Other part of pairlis below');
printval(first(first(rest(e))));
writeln;
writeln('B is below');
printval(first(rest(first(rest(e)))));
writeln;
end;*)

(*First, evaluate actual parameters and then form the environment
  of evaluation for the let statement*)
T:= pairlis(evlis(first( first( rest(e))), a),
            evlis( first(rest( first( rest(e))), a), a) );
writeln('The reference cnt of T is ',T@.ref);
eval := eval( first( rest (first(rest(e))), T);
end
else begin
  errormsg('eval', 7);
  writeln(e1);
  writeln;

```

```

        end
    end;
    decr(e);
    decr(a);
    decr(e1p);
    end (*Function eval*);

    (*****
    * Function letrec
    *
    * Purpose: Builds an environment for a recursive function.
    *
    * Calls: empty, cellcount, freecell, ptrassn, cons, decr
    *
    * Called by: eval
    *****
    function letrec;
        var S,C,B,Z,L,M:list;
        begin
            writeln('Entering letrec ref cnts for f,lam,bdy,a ',f@a.ref);
            writeln(' ',lam@a.ref);
            writeln(' ',bdy@a.ref);
            writeln(' ',a@a.ref);
            if f <> nil then
                l@a.ref := f@a.ref + 1;
            end
        end
    end
    )

```

```

if lam <> nil then
    lam@.ref := lam@.ref + 1;
    if bdy <> nil then
        bdy@.ref := bdy@.ref + 1;
        if a <> nil then
            a@.ref := a@.ref + 1;
        (*This procedure creates the proper environment for the evaluation
        of a recursive function call and evaluates the body of the letrec.
        The environment must include the body of the function itself
        tagged with the name of the recursive function.*)
        if diags then begin
            writeln;
            writeln('IN function letrec');
            (*writeln(' f is below ');
            printval(f);*)
            writeln;
            writeln(' lam is below');
            (*printval(lam);
            writeln;
            writeln(' bdy is below');
            printval(bdy);*)
            writeln;
            end; (*if diags*)
        if empty then begin

```

```

    new(L, lst); cellcount(1, 'letrec') end
  else L := freecell;
  if empty then begin
    new(B, lst); cellcount(1, 'letrec') end
  else B := freecell;
  if empty then begin
    new(Z, lst); cellcount(1, 'letrec') end
  else Z := freecell;
  if empty then begin
    new(C, alf); cellcount(1, 'letrec') end
  else C := freecell;
  if empty then begin
    new(M, lst); cellcount(1, 'letrec') end
  else M := freecell;
  if empty then begin
    new(S, lst); cellcount(1, 'letrec') end
  else S := freecell;

```

(*Create an attribute value pair with the function name as the attribute and a closure as the value and add this to the current environment.

The unique thing about this closure is that the ep part of the closure points back to the front of the current environment to enable a recursive call of the function*)

```
with C@ do begin
```

```
  ref := 0;
```

```

tag:= alf;
aval:= 'closure';
end;

with L@ do begin
  ref := 1;
  tag:= lst;
  ptrassn(head, Z);
  ptrassn(tail, a);
end;

with M@ do begin
  ref := 0;
  tag:= lst;
  ptrassn(head, L);
  tail:= nil;
end;

with B@ do begin
  ref := 0;
  tag:= lst;
  ptrassn(head, cons(C, lam));
  ptrassn(tail, M);
end;

with S@ do begin
  ref := 0;
  tag := lst;

```

```

end; (*Function apply*)

(*****
 * Function dcprim (Declare Primitive)
 *
 * Purpose: Builds an environment for primitive function calls.
 *
 * Calls: cellcount, cons
 *
 * Called by:
 *****)
function dcprim (primname:alfa; primitives:list): list;
  var C,D,E: list;
  begin
    (*At this point, there is no reason to check the free list since this
    is the very start of the program*)
    new (C, alf);
    new (D, alf);
    new (E, alf);
    cellcount(3, 'dcprim');
    with C@ do begin
      ref := 0;
      tag := alf;
      aval := primname;
    end;
  end;
end;

```

```

writeln('IN function apply; the function is: ');
printval(first(f));
writeln;
writeln('  in apply the arguments are:');
printval(x);
writeln;
end; (*if diags*)
ptrassn(f1p, first(f));
f1 := f1p@.aval;
if f1 = 'prim' then
  apply:=applyprim(rest(f), x)
else begin
  temp := eval( first(rest(rest(first(f))))),
    pairlis( first(rest(rest(first(f))), x, first(rest(f)) ));
  if callonly or diags then begin
    writeln('  in apply results below:');
    printval(temp);
    writeln;
  end;
  apply := temp;
end;
decr(f);
decr(x);
(*decr(f1p);*)

```

```

* Function apply (Apply any function to its arguments) *
*
* Purpose: Determines whether the body of a 'call' expression is a
* primitive call or an abstraction (closure). If the function
* is a primitive, the function name and the arguments are sent
* to function applyprim for evaluation. If a closure is de-
* tected, actual values are bound to variables and added to
* the current environment before evaluation.
*
* Calls: ptrassn, applyprim, first, rest, pairlis, decr
*
* Called by: eval
*****
function apply;
  var f1p, temp: list;
      f1: alfa;
  begin
    writeln('IN apply f coming in its ref cnt is ', f@.ref);
    if f <> nil then
      f@.ref := f@.ref + 1;
    if x <> nil then
      x@.ref := x@.ref + 1;
    if callonly or diags then begin
      writeln;

```

```

else if f1 = 'GT' then
    applyprim := GT(first(x), first(rest(x)))
else if f1 = 'LT' then
    applyprim := LT(first(x), first(rest(x)))
else if f1 = 'GE' then
    applyprim := GE(first(x), first(rest(x)))
else if f1 = 'LE' then
    applyprim := LE(first(x), first(rest(x)))
else if f1 = 'sin' then
    applyprim := sinp(first(x))
else if f1 = 'cos' then
    applyprim := cosp(first(x))
else if f1 = 'tan' then
    applyprim := tann(first(x))
else if f1 = 'cot' then
    applyprim := cot(first(x))
else if f1 = 'sec' then
    applyprim := sec(first(x))
else if f1 = 'csc' then
    applyprim := csc(first(x));
decr(f);
decr(x);
end; (*Function applyprim*)

```

```

(*****

```

```

    applyprim := cons(first(x), first(rest(x)))
end
else if f1 = 'conr' then
    applyprim := conr(first(x), first(rest(x)))
else if f1 = 'atom' then
    applyprim := atom( first(x))
else if f1 = 'null' then
    applyprim := null( first(x))
else if f1 = 'len' then
    applyprim := len( first(x))
else if f1 = 'sum' then
    applyprim := sum(first(x), first(rest(x)))
else if f1 = 'subt' then
    applyprim := subt(first(x), first(rest(x)))
else if f1 = 'prod' then
    applyprim := prod(first(x), first(rest(x)))
else if f1 = 'divi' then
    applyprim := divi(first(x), first(rest(x)))
else if f1 = 'sub' then
    applyprim := sub(first(x), first(rest(x)))
else if f1 = 'memb' then
    applyprim := memb(first(x), first(rest(x)))
else if f1 = 'equal' then
    applyprim := equal(first(x), first(rest(x)))

```

```

writeln('IN applyprim this is going to rest');
printval(first(x));
writeln;
end;
applyprim := rest( first(x))
end
else if f1 = 'repr' then begin
    if isfinset(x) then
        applyprim:= rest( first(x))
    else
        errormsg('apprim', 12)
    end
else if f1 = 'initial' then
    applyprim := initial( first(x))
else if f1 = 'cons' then begin
    if diags then begin
        writeln('Sending the next 2 lines to cons');
        printval (first(x));
        writeln;
        writeln;
        printval(first(rest(x)));
        writeln;
        writeln;
        end;
    end;

```

```

if f <> nil then
    f@.ref := f@.ref + 1;
if x <> nil then
    x@.ref := x@.ref + 1;
if callonly or diags then begin
    writeln;
    writeln('IN function applyprim; the function delivered is: ');
    printval(f);
    writeln;
    writeln(' in applyprim x is:');
    printval(x);
    writeln;
    writeln;
end;
ptrassn(f1p, first(f));
f1:=f1p@.aval;
if f1 = 'id' then
    applyprim := first(x)
else if f1 = 'first' then
    applyprim := first( first(x))
else if f1 = 'last' then
    applyprim := last( first(x))
else if f1 = 'rest' then begin
    if diags then begin

```

```

(*x is a finite set if the first element is 'finset'*)
isfinset := x[0].aval = 'finset'

end

end; (*Function isfinset*)

```

```

(*****
* Function applyprim (Apply primitive function)
*
* Purpose: Determines the primitive function to be used (f) and applies
* it to the arguments (x), e.g., as in standard function nota-
* tion f(x).
*
* Calls: ptrassn, first, last, rest, repr, errormsg, initial, cons, sub,
* memb, equal, subt, prod, divi, GT, LT, LE, GE, sin, cos, tan,
* cot, sec, csc, decr, conr, atom, null, len, sum
*
* Called by: apply
*****
function applyprim (f, x:list): list;
var flp:list;
    fl:alfa;
begin
    writeln;
    writeln('IN applyprim f refcnt is ',f@.ref);
    writeln('IN applyprim x refcnt is ',x@.ref);

```

```

        end;
        memb := C;
    end
end; (*Function memb*)

(*****
* Function isfinset
*
* Purpose: Determines whether a list is a finite set by checking the
*         first element of the list.
*
* Calls: first, errmsg,
*
* Called by: applyprim
*****
function isfinset (x:list): boolean;
var x1: list;
begin
    if x = nil then
        errmsg('isfinset', 1)
    else begin
        x1 := first(first(x));
        if x1.tag <> alf then
            errmsg('isfinset', 10)
        else

```

```

* Function memb (Member)
*
* Purpose: Creates a cell to hold the Boolean response from a call to
*         function membp.
*
* Calls: empty, cellcount, freecell, membp
*
* Called by: applyprim
*****
function memb(x, L:list): list;
  var C:list;
  begin
    if L = nil then
      errormsg('memb', 1)
    else begin
      if empty then begin
        new(C, boo);
        cellcount(1,'memb');
      end
    else
      C := freecell;
      with C@ do begin
        ref := 0;
        tag := boo;
        bval := membp(x, L);

```

```

else
    evlis := ccns( eval( first(L), a), evlis( rest(L), a));
end; (*Function evlis*)

(*****
* Function membp
*
* Purpose: Works in tandem with function memb to determine if x is a
*         member of list L.
*
* Calls: nullp, equalp, first, rest
*
* Called by: memb
*****
function membp(x, L:list):boolean;
begin
    if nullp(L) then
        membp := false
    else if equalp(x, first(L)) then
        membp := true
    else
        membp:= membp(x, rest(L))
    end; (*Function membp*)
)
(*****

```

```

else begin
    (*Evaluate false consequent*)
    if diags then begin
        writeln;
        writeln('in evcon evaluating false consequent next');
    end;
    evcon := eval( first(rest(first(L))), a);
end;
decr(B);
end; (*Function evcon*)

(*****
* Function evlis (Evaluate List)
*
* Purpose: Evaluates a list of arguments and constructs a list of the
*           of the results.
*
* Calls: nullp, cons, eval, evlis
*
* Called by: eval, evlis
*****
function evlis;
begin
    if nullp(L) then
        evlis := nil

```

```

* Called by: eval
*
*****
function evcon;
  var B: list;
  begin
    (*Evaluate condition*)
    B:= eval( first(first(L)), a);
    if diags then begin
      writeln;
      writeln('IN function evcon the condition evaluated to: ');
      printval(B);
    end;
    if B=nil then
      errmsg('evcon', 8)
    else if B@.tay <> boo then
      errmsg('evcon', 9)
    else if B@.bval then begin
      (*Evaluate true consequent*)
      if diags then begin
        writeln;
        writeln('in evcon evaluating true consequent next');
      end;
      evcon := eval( first(rest(first(L))), a);
    end
  end
*****

```

```

ptrassn(head, B);
tail := nil;
end;
with Z@ do begin
    ref := 0;
    tag := 1st;
    ptrassn(head, f);
    ptrassn(tail, S);
end;
(*Evaluate the call to the recursive function in the created
environment*)
letrec := eval(bdy, L);
end; (*Function letrec*)

```

```

(*****
* Function evcon (Evaluate Conditional)
*
* Purpose: Evaluates a conditional expression (consists of three
*          sublists: condition, true consequent, and false conse-
*          quent) by first determining the result of the condition
*          and then evaluating the true consequent or the false conse-
*          quent.
*
*
* Calls: eval, errormsg, first, rest, decr
*)

```

```

with D@ do begin
    ref := 0;
    tag := alf;
    aval := 'prim';
end;

with E@ do begin
    ref := 0;
    tag := alf;
    aval := primname;
end;

dcprim := cons(cons(C,cns(cons(D,cons(E,nil)),nil)),primitives);
end; (*Function dcprim*)
(*****
* Function readfname (Read file name)
*
* Purpose: Reads the name of a file that contains an ELC program. The
*          filename is input interactively and may be up to eighty
*          eighty characters long.
*
*
* Calls: None
*
* Called by: main program
*****
function readfname: filename;

```

```

var c: char;
temp: filename;
i: integer;

begin
  i := 1;
  while c <> ' ' do begin
    read(c);
    temp (.i.) := c;
    i := i + 1;
  end;
  readfname := temp
end; (*readfname*)

begin (*Main Program*)
  newcells := 0;
  (*Initialize the header record of the freelist*)
  with hdr do begin
    numcells := 0;
    next := nil;
  end;
  (*Initialize the array for the cell creation information*)
  for k := 1 to 26 do begin
    with counts(.k.) do begin
      modul := 'empty';
      cellcnt := 0;
    end;
  end;
end;

```

```

end;

end;

(*Build the association list for the primitive operations*)
primitives := nil;
primitives := dcprim('first', primitives);
primitives := dcprim('last', primitives);
primitives := dcprim('initial', primitives);
primitives := dcprim('rest', primitives);
primitives := dcprim('cons', primitives);
primitives := dcprim('conr', primitives);
primitives := dcprim('atom', primitives);
primitives := dcprim('null', primitives);
primitives := dcprim('sum', primitives);
primitives := dcprim('subt', primitives);
primitives := dcprim('prod', primitives);
primitives := dcprim('divi', primitives);
primitives := dcprim('sub', primitives);
primitives := dcprim('equal', primitives);
primitives := dcprim('len', primitives);
primitives := dcprim('GT', primitives);
primitives := dcprim('LT', primitives);
primitives := dcprim('GE', primitives);
primitives := dcprim('LE', primitives);
primitives := dcprim('sin', primitives);

```

```

primitives := dcprim('cos', primitives);
primitives := dcprim('tan', primitives);
primitives := dcprim('cot', primitives);
primitives := dcprim('sec', primitives);
primitives := dcprim('csc', primitives);
primitives := dcprim('id', primitives);
primitives := dcprim('repr', primitives);
primitives := dcprim('memb', primitives);
primitives@.ref := 1;
writeln;
diags := false;
interac := false;
ch := ' ';
(*Ask user initial questions to see if a trace is requested.*)
date(dtmoyr);
time(curtime);
writeln('Functional Language Interpreter (ELC): ');
writeln(' version 12.0');
writeln(' date/time ', dtmcyr, ', ', curtime);
writeln;
(*Determine whether the program is to be interactively typed in or read
from a file by checking the number of arguments on the command line.
If there are two arguments and the second one is 'i' the session is to
be interactive, otherwise, prompt the user for the filename (1..80 char) *)

```

```

if argc = 1 then begin
    writeln('File ELC program to be read from: ');
    filearg := readfname;
    reset(infile, filearg);
end
else if argc = 2 then begin
    argv(1, filearg);
    if filearg = 'i' then begin
        interac := true;
        writeln('Note: '!' ends an interactive terminal session');
    end
    else
        reset(infile, filearg)
    end;
    writeln('Total program trace ? type in 't'');
    writeln('Monitor function calls only? type in 'c'');
    writeln(' If no trace, type any other key');
    readln(ans);
    if ans = 't' then diags := true
    else if ans = 'c' then callonly := true;
    while ch <> '!' do
        begin
            writeln;
            writeln('Enter Expression');

```

```

noublank;
if ch <> '!' then begin
    temp := readval;
    if diags then begin
        writeln('Expression after reading');
        printval(temp);
        writeln;
    end;
    printval( eval( temp,primitives));
end;

        writeln(' ');
end;

writeln('Evaluation Completed');
writeln;
(*Print the amount of user and system time taken by the program*)
writeln('*****');
writeln('
        Statistics');
(*Sysclock and clock are built-in Berkeley Pascal function to show
System time = The amount of time that was spent inside the Unix
        system itself, doing work on behalf of the user's
        program.
User time = The amount of time actually spent obeying the instruc-
        tions in the user's program*)
writeln('System time was ',sysclock:10,' milliseconds');

```

```

writeln('User time was ',clock:10,' milliseconds');
l:= 1;
writeln;
writeln('-----+');
writeln('|Module      Cells created |');
writeln('|-----|');
(*Print out the contents of the array containing the cell creation
information.*)
while counts (.l.).modul <> 'empty' do begin
  with counts(.l.) do
    writeln('|',modul,' ',cellcnt,' |');
  l := l+1;
end;
writeln('-----+');
writeln(' Total cells ',newcells);
writeln;
end. (*Program func*)

```

LIST OF REFERENCES

1. Naval Postgraduate School Technical Report NPS52-81-012, Elements of Programming Linguistics, Part I, The Lambda Calculus and its Implementation, by B. J. MacLennan, Monterey, CA, August 1981.
2. Backus, J., "Can Programming be Liberated from the von Neumann Style? A Functional Style and its Algebra of Programs," Communications of the ACM, V21, no. 8, 1978.
3. Stone, H. S., Introduction to Computer Architecture, Science Research Associates, 1980.
4. Darlington, J., Functional Programming and Its Applications. An Advanced Course, Cambridge University Press, England, 1982.
5. Stanford University Technical Report STAN-CS-73-403, Hints on Programming Language Design, by C. A. R. Hoare, Palo Alto, CA, December 1973.
6. MacLennan, B. J., Functional Programming Methodology: Theory and Practice, To be published by Addison Wesley.
7. Early, G., "Functional Programming and the Two-Pass Assembler," Sigplan Notices, V17, No. 8, 1982.
8. Douglas, John, H., "New Computer Architectures Tackle Bottleneck," High Technology, June 1983.
9. Cooper, D., Oh! Pascal!, W. W. Norton and Company, 1982.
10. MacLennan, B. J., Principles of Programming Languages, Holt, Rhinehart and Winston, 1983.

BIBLIOGRAPHY

- Baden, S., "Berkely FP Experiences with a Functional Programming Language," Spring Compcon 83, Intellectual Leverage for the Information Society, IEEE, 1983.
- Boecker, H., "Functional Programming in Basic-Plus," Computers in Education, North-Holland Publishing Company, 1981.
- Berkling, K., "A Consistent Extension of the Lambda-Calculus as a Base for Functional Programming Languages," Information and Control, V55, 1982.
- Durham, T., "Asserting Assertional Style," Computing, March 1983.
- Fehr, Elfriede, "The Simplest Functional Programming Language is Neither Simple nor Functional," SIGPLAN Notices, V18, 4, April, 1983.
- Gram, C., "Easy Functional Programming," Norodata 81, V1, 1981.
- Inoue, K., "Implementation of a Functional Programming Language FPL," Transcripts of the Institute for Electronics and Communications Engineering Japan, VE65, May 1982.
- Islam, N., "Transforming Functional Programs," Micro-Delcon 82: The Delaware Bay Computer Conference, IEEE, 1982.
- Kennaway, J. R., Parallel Implementation of Functional Languages, Proceedings of the 1982 International Conference on Parallel Processing, 1982.
- MacLennan, B. J., "Values and Objects in Programming Languages," SIGPLAN Notices, V17, 12, December, 1982.
- Nagata, M., "An Approach to Construction of Functional Programs," Journal of Information Processing, V5, No. 4, 1982.
- Organick, E. I., "New Directions in Computer Systems Architecture," Euro-micro, Journal 5, 1979.
- Spector, David, "The Simplest Functional Programming Language," SIGPLAN Notices, V18, 1, January 1983.
- Stabile, L. A., FP and Its Use as a Command Language, Proceedings of Distributed Computing, Compcon 80, Twenty-First IEEE Computer Society International Conference, 1980.

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