

## Icon Implementation Notes\*

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### ABSTRACT

Icon is a new general-purpose programming language intended for nonnumeric applications, especially those involving string and structure processing. This report describes some aspects of the Ratfor implementation of Icon, Version 2.0. Included are a brief overview of the implementation, an explanation of the translator organization and generated code, a description of the runtime environment, and a summary of programming conventions and peculiarities.

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### 1. Introduction

Icon is a new general-purpose programming language intended for nonnumeric applications, especially those involving string and structure processing. Much of the philosophical basis of Icon comes from its predecessors, SNOBOL4 [1] and SL5 [2]. This report describes some aspects of the implementation of Version 2.0 of Icon. Further details concerning the language and its use may be found in Refs. [3-5]; additional implementation details are given in Refs. [5,6].

The Icon system consists of two major parts: a translator and a runtime system. The translator compiles an Icon program into a program in the target language. The runtime system contains all of the routines referenced by this program. Currently, Fortran is the target language. Thus, running an Icon program requires translating it into Fortran, compiling the Fortran program, and loading it with the previously compiled routines from the runtime system.

### 2. The Translator

The translator transforms Icon source text into Fortran code. This code consists mainly of calls to subroutines that implement the semantics. Each Icon procedure is translated into a corresponding Fortran subroutine. There is also a Fortran subroutine, generated by the translator, that controls transfer of control. The format of the generated subroutines is described in Appendix A.

The translator consists of three parts: the lexical analyzer, the parser, and the code generator.

#### 2.1 The Lexical Analyzer

The lexical analyzer makes two passes. The first pass builds the symbol table, procedure and record blocks, and resolves undeclared identifiers. In addition, it processes include statements and generates a listing if requested. The results of the first pass are data structure tables and a file containing the source text broken down into tokens (no declaration information is included). The format of each line of the file is

token subtype

where "token" is a number representing a token and "subtype" is a number representing additional information about the token. For example, if token represents a literal (INT, FLOAT, or STRING), subtype is the index of the literal in the appropriate literal table. If token represents an operator class (INFIX, PREFIX, SUFFIX), subtype describes the specific operator. If

token signifies an identifier (ALPHA), subtype is the index of the identifier in the identifier table. If token represents a keyword (LEXKEY), subtype identifies the specific keyword. Finally, subtype is the same as token for reserved words and keywords. Locations of newlines in the source program are also noted in the token file by including a token representing newline (NEWLINE) with the line number as the value of subtype.

The second pass reads from the token file a token at a time as requested by the parser.

## 2.2 The Parser

The parser is a recursive descent parser, derived from a context-free grammar for the language. In general, this grammar contains left-recursive productions. These are transformed using the technique described in Ref. [7]. As an example of this technique, the production (note the left recursion)

```
MULOP  -->  MULOP '*' EXPOP
```

becomes

```
MULOP  -->  EXPOP MULOPP
MULOPP -->  '*' EXPOP MULOPP
          |  eps
```

Appendix B contains a transformed grammar for Icon.

Recursive descent is usually implemented by writing a recursive procedure for each nonterminal in the grammar [8]. Since Icon is implemented in Ratfor, implementation of recursive procedures was not possible. Instead, a methodology that explicitly simulates recursion is used. As a result, the entire parser is contained in one subroutine. Recursive procedures are simulated using labeled code segments, explicit push and pop operations, and a computed goto for dispatching to return points. The general form of the parser subroutine is as follows.

```

repeat {
  call pop(case)
  goto (...
    labels for all nonterminal routines
    and all possible return points
    ...), case

nonterminal1
  ... code ...
  next

nonterminal2
  ... code ...
  call push(return21)
  goto nonterminalx
return21
  ... code ...
  next
  ...

nonterminaln
  ... code ...
  next
}

```

The nonterminal code segments are written in much the same way as would recursive procedures in the usual implementation of recursive descent. As the code segments above indicate, the main difference is the need to stack the return label prior to "calling" a code segment for another nonterminal. For example, the code segment for multiplication operators derived from the syntax fragment given above is as follows.

```

MULOP
  call push(MULOPP)
  goto EXPOP      ≠ "call"
MULOPP
  while (token == OMUL) {
    call push(MULOPPl)
    goto EXPOP
MULOPPl
  continue
  }
next

```

The parser operates on a single Icon procedure and returns a parse tree for that procedure. The parse tree is a directed graph of connected nodes generated during parsing. Each node may have from one to eight fields depending on the semantics of the object represented by that node. The information placed in these fields is constrained by type: labels, pointers, and data. Data may not be placed in pointer fields nor pointers placed in data fields. The value of the variable ptree is the pointer to the current parse tree. When invoking other nonterminal functions the value of ptree must be saved on

the stack along with the return label. Unlike the return label, which is popped automatically, the saved value ptree must be popped explicitly. A node is assigned to ptree upon the completion of the processing for each nonterminal. For example, for the multiplicative operators the "continue" in the above code is replaced by

```
ptree = node5(CINFIX, t, tn, e, ptree)
```

where e is a pointer to the parse tree for the left side of the operator and ptree (inside the function call) is a pointer to the right side.

In addition to ptree, there are several other important variables global to the parser.

The value of the variable fail indicates whether or not an expression can fail. As described in Section 3.3, expressions that can fail require additional code to drive them. This, in turn, requires that an additional node be produced during parsing to indicate the need for the driving code. Thus, many of the nonterminal code segments in the parser save and restore fail if necessary.

The value of the variable var indicates whether not an expression is a variable. This value is used in those code segments that deal with operators, such as assignment, that change the value of program variables.

The value of the variable type indicates the data type of the current expression. Type is used to determine which runtime type conversions, if any, are required.

The values of the variables brklab and nxtlab contain the labels used in break and next expressions. A zero value indicates an improper context for break or next.

### 2.3 The Code Generator

The code generator produces the Fortran code for a single Icon procedure. It takes as input the parse tree and generates code while traversing the tree in preorder. Since tree traversal is a recursive process, the recursion is simulated using a technique similar to that used in the parser. The targets of the recursive calls in the parser are determined by the grammar and are constant. The targets in the code generator, however, are determined by the configuration of the parse tree. This is handled by placing the label of the next code segment on the stack in addition to the return point. The general form of the code generator is as follows.

```

call push(CDONE)           ≠ set end marker
call push(heap(ptree+NTYPE)) ≠ type of first node
while (ptree > 0) {
  call pop(case)           ≠ current node or label
  goto (...
    labels of parse tree nodes
    and of return points
    ...), case

Cnode
  el = heap(ptree+NPTR1)   ≠ leftmost subtree
  call push(ptree)        ≠ save current parse tree
  call push(Cnode1)       ≠ save return point
  call push(heap(el+NTYPE)) ≠ type of first node
  ptree = el              ≠ reset parse tree
  next

Cnode1
  call pop(ptree)         ≠ restore parse tree
  call printx("C output code%n$0", 0, 0)
  next                    ≠ "return"
  ...

CDONE                      ≠ end marker
  break
}

```

Appendix C gives the form of the generated code for each language construct.

### 3. The Runtime System

The bulk of the Fortran program generated by the translator consists of calls into the runtime system. The runtime system is a set of subroutines that implements the built-in operations in the language. There are also many utility subroutines, including the storage management subsystem, for example.

Operation of the runtime system revolves around a system stack. Functions in the runtime system get their arguments from the stack and leave results there. Activation records for procedures are also placed on the stack. In addition, the storage management system uses the stack as a starting point for locating accessible data objects during reclamation.

Generators are implemented using the common two-stack model for implementing backtracking [9]. The second stack, called the control stack, is used to hold information associated with dormant generators. The system stack could be used to hold this information without the elaborate threading [10] required in more general cases. This simplification, which is used in Ucon (a more recent implementation of Icon for the PDP-11), is possible because the semantics of Icon generators imply that the two stacks operate in parallel.

The following sections describe the representation of data, the organization of storage at runtime, and the operation of some of the subroutines in the runtime system.

### 3.1 Data Representation and Storage Organization

Storage is represented by the Fortran array mem. Mem is divided into five regions roughly corresponding to the division of data types into classes. These regions are depicted in Figure 1.

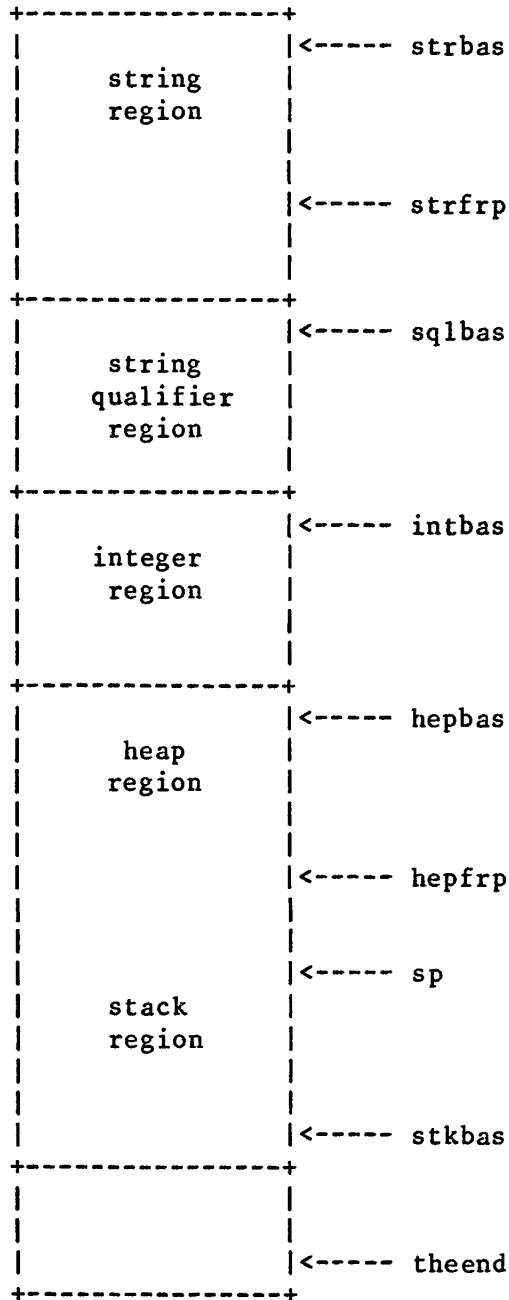


Figure 1. Storage Regions.

All source-language values have a uniform representation: an index into mem (indices into mem are often referred to as pointers). The type of a value



is determined by the region to which it refers, e.g. if the value is within the bounds specified by intbas and hepbas, it is an integer.

The structure, allocation algorithm, and reclamation technique of each region is determined by the kind of data stored in that region.

Integers are represented by pointers into the integer region. Each cell in the region contains one integer. The lower portion of the region houses a range of permanently allocated integers; the typical range is -1 to 100. A linked list of free cells in the integer region is maintained; allocation consists of simply returning the first free integer on this list.

Strings are represented by pointers into the string qualifier region. A string qualifier is a two-cell block containing the length of the string and the character offset from the beginning of mem to the first character in the string. The actual string is stored in the string region [11,12]. A qualifier for the null (zero-length) string is permanently allocated as the first qualifier in the qualifier region. Allocation of qualifiers is similar to allocation of integers; a linked list of free qualifiers is maintained. For the string region, a free space pointer is maintained (strfrp, see Figure 1). Allocation is done by simply incrementing strfrp by the amount of the request.

All aggregates (e.g. lists, tables, records) are stored in the heap. Storage in the heap is allocated in self-identifying blocks. All pointers into the heap point to the head of a block. There are four block layouts, depending on whether the block contains pointers (called "floating addresses") and is varying or fixed size. The four variations are shown in Figure 2.

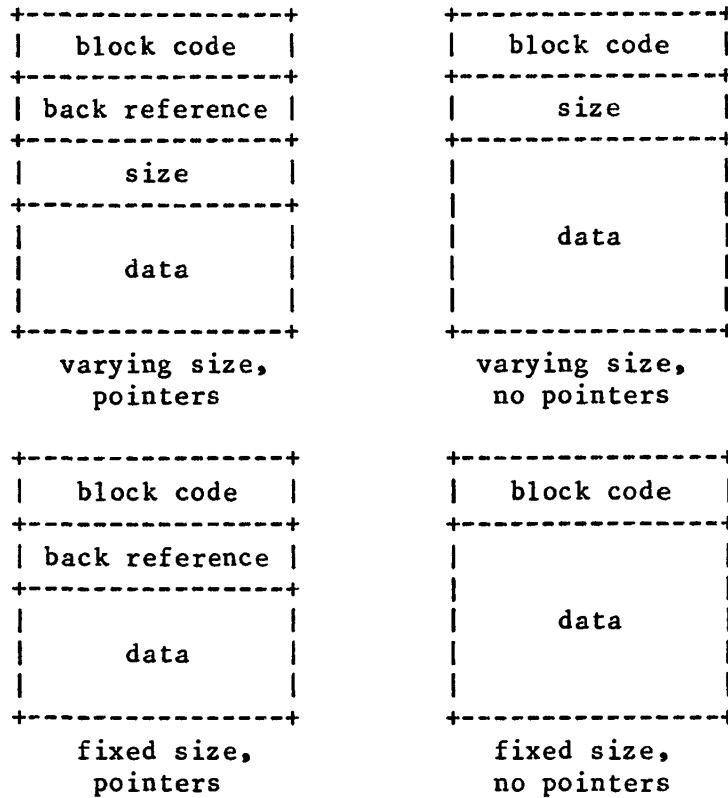


Figure 2. Block Layouts.

Allocation in the heap is performed by incrementing the free space pointer `hepfrp` (see Figure 1) by the amount of the allocation request.

The stack grows from `stkbas` backwards towards `hepfrp` (see Figure 1); `sp` indicates the top of the stack. Variables and values on the stack are represented by two-cell blocks as depicted in Figure 3.

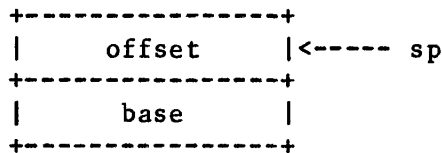


Figure 3. Stack representation of variables and values.

The meanings of `base` and `offset` are summarized in Table 1.

Table 1. Base and Offset for Variables and Values.

```

=====
base  base  size  offset  meaning
      symbol
-----
>0           2   <0   value is mem(base-offset)

  0           2           value is offset

-1  TVNONE   2           not used

-2  TVLCL   2   <0   value is mem(cfp+offset)

-3  TVPOS   2           value is &pos

-4  TVRAND   2           value is &random

-5  TVSUBS   6   <0   value is substr(s,i,l):
                        -offset-1 is i
                        mem(sp+2) is value of s
                        -mem(sp+3)-2 is l
                        mem(sp+4) is offset for s
                        mem(sp+5) is base for s

-6  TVSUBJ   6   <0   value is substring of &subject:
                        -offset-1 is i
                        mem(sp+2) is value of s
                        -mem(sp+3)-2 is l
                        -mem(sp+4)-1 is new &pos or
                        mem(sp+4) is 0 if &pos is to
                        be positioned at end of the
                        replacement string
                        mem(sp+5) is 0

-7  TVTBL   6   <0   value is a table element t[e]:
                        -offset is hash bucket offset
                        mem(sp+2) is t
                        mem(sp+4) is e

-8  TVARRY   6   <0   value is open list element a[i]:
                        -offset-1 is i
                        mem(sp+4) is a
=====

```

Negative values of base indicate "trapped variables"; these represent kinds of access that requires special processing [13]. Note that several of the trapped variables occupy 6 stack cells.

Since the stack is used by the reclamation routines to locate accessible data, it is essential that "junk" -- anything that is not a valid pointer -- never get pushed onto the stack. There are, however, cases in which it is necessary to push arbitrary integer data, such as return labels, onto the stack. This is done by preceding such data by -1 and a count of the number of junk cells that follow. For example, Figure 4 shows the stack configuration

after pushing the junk values 52 and -104.

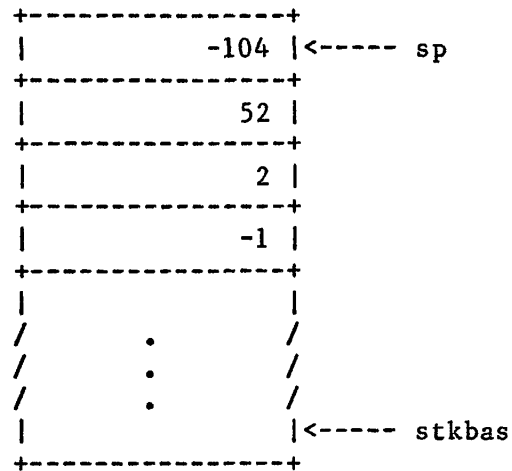


Figure 4. Stack Configuration After Pushing 52 and -104.

Figures depicting the representation of all types of data are given in Appendix E.

### 3.2 Reclamation

Reclamation of storage in each region consists of identifying the accessible data in that region, and restructuring the region so that the space occupied by inaccessible data is made available for reuse. Determining the accessible data in any region starts by examining the contents of a set of locations that may contain pointers; these locations are called tended locations. The tended locations include the system stack and about two dozen specific locations in the labeled common ctend.

Reclamation in the integer region consists of "sweeping" the tended locations and the heap for integers. Prior to sweeping, a bit map of the integer region is pushed onto the stack; this is used to record accessible integers.

Reclamation in the qualifier region is similar to that in the integer region. The bit map is not needed, however. Accessible qualifiers are "marked" by setting their location fields to  $-(\text{location}+1)$  (the location field of free qualifiers is -1).

Reclamation in the string region consists of sorting pointers to the active qualifiers by their location fields, and compacting accessible strings into the lower part of the string region. The complete algorithm is given in Ref. [12].

Heap reclamation is performed using the SITBOL compactifying garbage collection algorithm [13]. There is an important aspect of this scheme that had a significant effect on the implementation. The marking phase of the algorithm constructs a linked list of pointers to every accessible block. For each such block, this list begins at its type code field (see Figure 2). One

problem is that pointers are simply indices into mem and consequently pointers to the tended locations in ctend are not easily represented. In order to address the tended values, the values in ctend are copied to reserved locations at the base of the stack prior to marking, and the updated values are copied back upon completion.

The second problem is that pointers are indistinguishable from type codes, which terminate the linked lists mentioned above. Thus, the heap must be positioned in mem so that all pointers into the heap have values greater than the largest type code value.

Further details concerning reclamation are given in Ref. [6].

### 3.3 Handling Failure

The system stack holds intermediate results. This presents a problem in the implementation of the immediate termination of an expression; it is necessary to be able to discard partially computed results that are no longer relevant. On entry to any expression that may fail (and only those expressions), the current height of the system stack is saved. When evaluation of the expression is completed (with either success or failure), the stack height is reset.

For any expression that may fail, the generated code is

```
      call xmark(MAXLABELS*p + n)
      .
      .
      <code for expression>
      .
      .
      n call xdrive
```

where p is the procedure number. The code

```
      if(signal.eq.0)goto 1
```

is emitted following every operation that may fail. In every procedure, the Fortran statement

```
      1 label=flabel
```

precedes the goto switch yard; thus transfer to the failure point is effected by transfer to label 1.

The purpose of xmark is to save the current heights of the system and control stack, the current value of flabel, and set flabel to the argument. These data are saved on the stack as depicted in Figure 5. The current heights of the system and control stacks are given by the values of marksp and markcp, respectively. In order to avoid problems during heap reclamation, marksp and markcp are saved as offsets from the base of the appropriate stack.

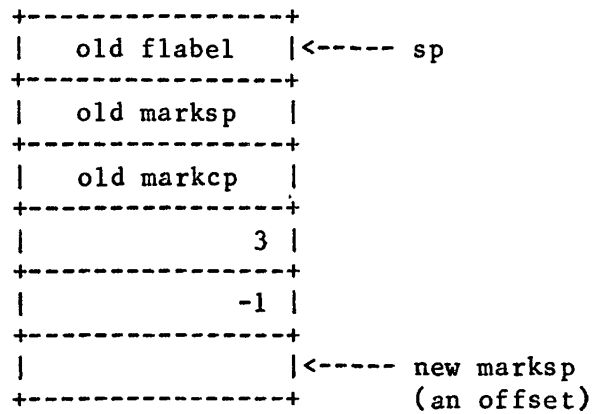


Figure 5. Stack after Call to xmark.

Using the current value of marksp, xdrive resets the stack heights and flabel to their saved values.

The routines xmark and xdrive are also used with generators; see Section 3.6.

### 3.4 Loops

The possibility of break and next appearing within loops is similar in nature to the possibility of failure in expressions. It is necessary to be able to discard partially computed results on the stack that are no longer relevant. Thus, every loop begins with

```
call xlpbeg
```

and ends with

```
call xlpemd
```

The purpose of xlpbeg is similar to that of xmark; it saves the appropriate data on the system stack as illustrated in Figure 6. The variable lptop is an offset to the saved data.

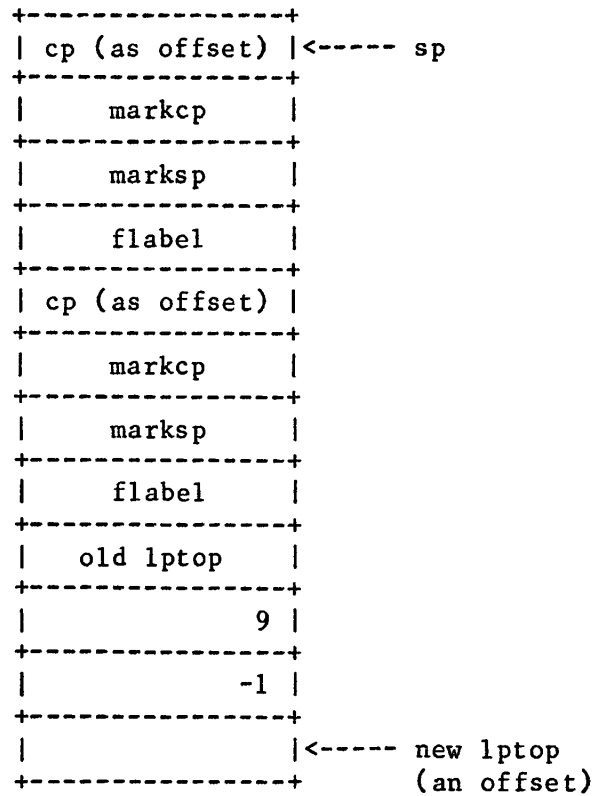


Figure 6. Stack after Call to xlpbeg.

The purpose of xlpbeg is similar to xdrive; it uses lptop to restore the data saved by xlpbeg. It also insures that null is returned by the loop expression.

The break expression simply causes a transfer to the statement containing the call to xlpbeg (see Appendix C). The next expression, however, calls xnext and then transfers to the code for the first statement in the loop. The routine xnext resets cp, markcp, marksp, and flabel using the data saved in the stack at lptop. It also discards partially computed results by setting sp to lptop - 11, which was the value of sp upon entry to the loop (after the call to xlpbeg). This latter action is actually incorrect for every loops; see Section 3.6.

As an example, consider a loop of the form

```

while ... do {
    ...
    break
    ...
    next
    ...
}

```

The general form of the generated code is

```

        call xlpbeg
23001  continue
        ...           ≠ evaluate condition
        if(signal.eq.0)goto 23002
        ...
        goto 23002    ≠ break
        ...
        call xnext    ≠ next
        goto 23001
        ...
        goto 23001    ≠ do next iteration
23002  call xlpend

```

Note that two copies of `cp`, `markcp`, `marksp`, and `flabel` are saved; this is necessary for proper execution of next in the every loop. This is described further in Section 3.6.

### 3.5 Procedure Activation

Activation records for procedures are placed on the system stack. Figure 7 shows the layout of activation records.



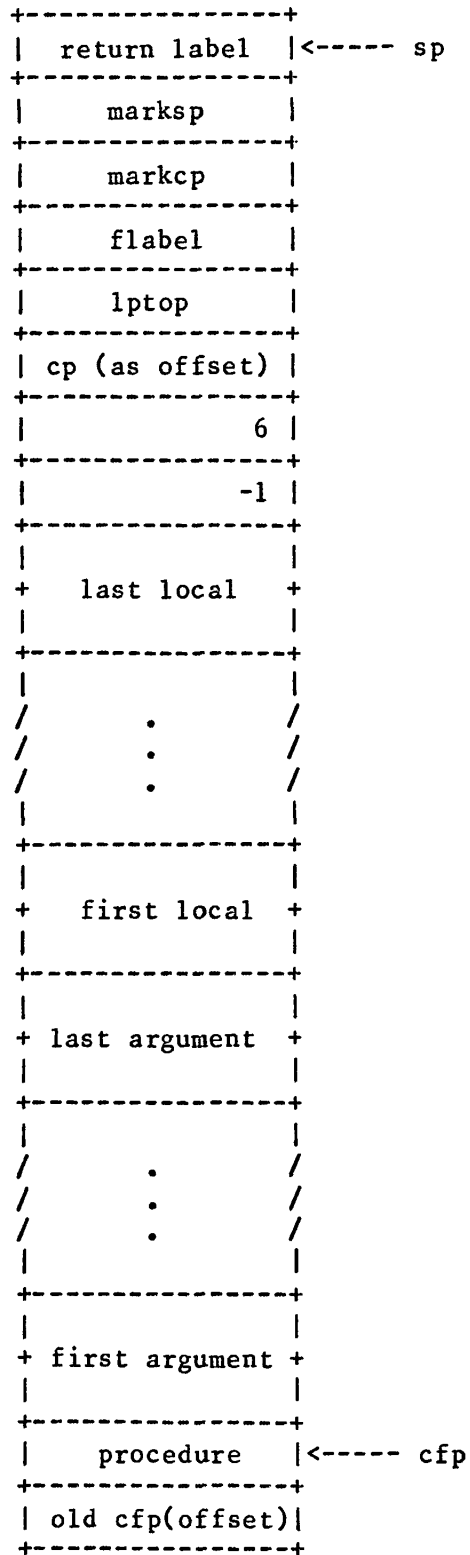


Figure 7. Layout of Activation Records for Procedures.

The base of the current activation record is indicated by cfp. Local

variables and arguments are accessed using offsets from cfp. Specifically, formal parameters are considered local variables, and the value of local variable  $i$  is found at  $\text{mem}(\text{cfp}-2*i)$ .

Note that the values of local variables occupy two cells in accordance with the convention described in Section 3.1. The physical location of a local variable changes if the stack is moved. Thus, local variable  $i$  (as opposed to its value) is represented as shown in Figure 8 (see also Figure 3 and Table 1).

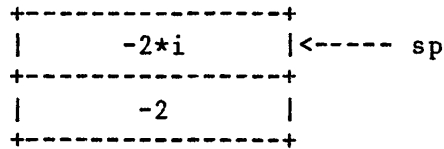


Figure 8. Stack Representation of Local Variable  $i$ .

Note that the value of  $-2*i$  is never  $-1$ , which would confuse the reclamation routines.

### 3.6 Generators

When a generator is invoked, it produces its first value and then prepares for the possibility of reactivation. This preparation involves saving data related specifically to the generation of alternatives (such as the bounds and increment in the to generator) and partially computed results that might otherwise be consumed before the generator is reactivated. A second stack, the control stack, is used for saving these kinds of data.

The data saved for a dormant generator is taken from the system stack. The precise amount of data saved is determined by the value of  $\text{marksp}$ . Specifically,  $\text{sp}$  and  $\text{marksp}$  delimit that portion of the system stack that contains partially computed results and data relevant to the generation of alternatives. For any expression containing generators, calls to  $\text{xmark}$  and  $\text{xdrive}$  are generated as they are for expressions that may fail. The call to  $\text{xmark}$  establishes the value of  $\text{marksp}$  that is used when data is pushed onto the control stack.

A generator "prepares for reactivation" by pushing any data it may need onto the system stack and calling  $\text{save}$ . This call causes all data from  $\text{sp}$  to  $\text{marksp}$  to be pushed onto the control stack. The layout of that data is depicted in Figure 9.

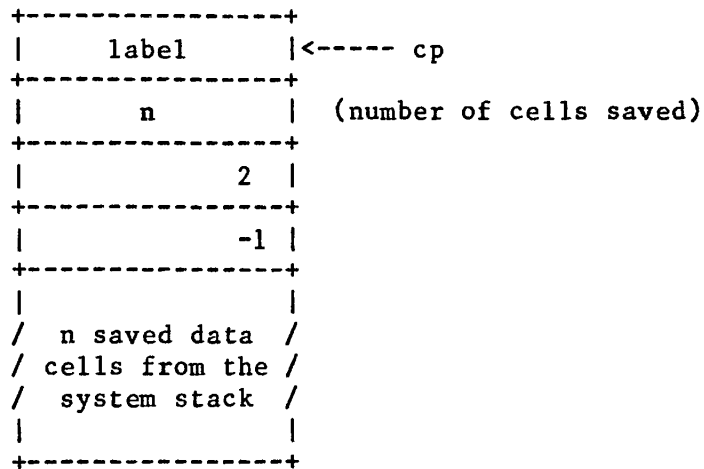


Figure 9. Control Stack after Call to save.

The label saved on the control stack (see Figure 9) is the label of the call to the generator. As described below, this is used to transfer control back to the generator so that it can generate alternatives.

Dormant generators are activated by a call to xdrive. Subroutine xdrive performs different functions depending on whether dormant generators exist or not. If the signal is failure and there are no dormant generators, xdrive behaves as described above (see Section 3.3). If dormant generators exist upon failure, xdrive activates the most recently suspended dormant generator.

The general outline of xdrive is as follows.

```

subroutine xdrive
  if (signal == 0 & dormant generators exist) {
    label = reactivation label of dormant generator
    restore system stack from top of control stack
  }
  else { ≠ expression succeeded or has no alternatives
    label = 0
    pop and save expression value off of system stack
    reset cp and sp from marksp and markcp
    restore marksp, markcp, & flabel from data saved by xmark
    push expression value onto system stack
  }
  return
end
  
```

The value of label after a call to xdrive indicates whether a generator is to be reactivated. If label is non-zero, it is the label to which control should be transferred. If label is zero, execution continues without transfer of control (note that xdrive does not change signal). Every call to xdrive is followed by the statement

```

if(label.ne.0)goto 2
  
```

in order to reactivate the dormant generator. Subroutine xdrive detects the presence of dormant generators by noting that the size of the control stack has increased since the last call to xmark. This is accomplished using the value of markcp set by xmark.

As mentioned above, generators save local data that is needed to compute alternatives by pushing this data onto the system stack and calling save. When the generator is reactivated, the system stack is restored to its state just prior to the call to save so that the generator may retrieve these saved data. A call to a generator results in Fortran code of the form

```
L call x????(MAXLABELS*p+L)
```

where p is the current procedure number and L is the reactivation label. In order to avoid having to write two routines for every generator (one for the initial activation and one for reactivation), the value of signal is used to determine the current phase of a generator. If the signal indicates success, the generator is being activated for the first time; it initializes itself and computes its first value. If the signal indicates failure, the generator is being reactivated; it restores its local data (now on the top of the system stack) and computes its next value. A general outline of this scheme is

```
subroutine x????(lab)
  if (signal == 1) {      ≠ initial call
    initialize local variables
  }
  else {                  ≠ reactivation call
    signal = 1 ≠ assume success
    restore saved local variables
  }
  generate next value
  if (generation succeeded) {
    push local variables onto system stack
    call save(lab)
    pop local variables off system stack
    push generated value onto system stack
  }
  else
    signal = 0      ≠ generation failed
  return
end
```

Note that the reactivation label -- the argument to a generator subroutine -- is passed along to save. The initialization of local variables usually involves using additional arguments passed on the system stack. These arguments are not saved, however. The information they convey is usually stored in local variables (perhaps in a different form) and saved by calling save. The form in which the local data is saved varies from generator to generator. For example, the to generator simply saves the current value and the limit as integers on the stack preceded by the -1 flag and a cell count.

As an example, the generated code for the expression

$x + 2 < (1 \text{ to } 5)$

is as follows, assuming the expression appears in procedure number 1 and MAX-LABELS is 1024.

```
call xmark(1028)      ≠ set 4 as failure label
call xlocal(1)       ≠ push x as a variable
call xderef          ≠ dereference to get value of x
call xcnumr          ≠ convert value to numeric
call xpintg(1)       ≠ push integer literal "2"
call xadd            ≠ add value of x + 2
call xpintg(2)       ≠ push integer literal "1"
call xpintg(3)       ≠ push integer literal "5"
5 call xto(1029)      ≠ generate 1 to 5
if(signal.eq.0)goto 1 ≠ failure if to is exhausted
if(xncmp(junk).ge.0)goto 1 ≠ compare top 2 numeric values
signal=1             ≠ reset signal after comparison
4 call xdrive        ≠ here on failure
if(label.ne.0)goto 2 ≠ jump to reactive generator
```

Alternation (|) requires a different implementation than other generators. Consider the expression  $e1 | e2$ ; if alternation were treated like other generators, the generated code would be something like

```
<evaluate e1>
<evaluate e2>
L call xalt(MAXLABELS*p+L)
```

The problem here is that if  $e1$  fails,  $e2$  would not be evaluated. In addition,  $e2$  is evaluated "too early" -- it should only be evaluated if a subsequent expression fails. The actual code for  $e1 | e2$  is of the form

```
L   if(signal.eq.0)goto 23001 ≠ if failure evaluate e2
    call save(MAXLABELS*p+L) ≠ save current state
    <evaluate e1>
    goto 23002                ≠ skip over e2
23001 signal=1                ≠ here on subsequent failure...
    <evaluate e2>             ≠ reset signal and evaluate e2
23002 continue
```

Generators are reactivated by `xdrive` only upon subsequent failure in the expression in which they appear. The every expression causes repeated activation of generators even if they succeed. Since every  $e$  is equivalent to

$e \ \& \ (1 = 0)$

and every  $e1 \ \text{do} \ e2$  is equivalent to

$e1 \ \& \ \{e2; 1 = 0\}$

every is implemented by simply setting the signal to 0 before the call to `xdrive`, thereby causing `xdrive` to reactivate dormant generators.

Specifically, the generated code for the expression

every e1 do e2

is of the form

```
        call xlpbeg      ≠ begin a loop
        call xmark(MAXLABELS*p+L)
        <evaluate e1>
        call xpop        ≠ discard value of e1
        call xevery      ≠ reset saved control stack height
        <evaluate e2>
        call xpop        ≠ discard value of e2
23001 continue
        signal=0        ≠ force failure
L      call xdrive      ≠ reactivation generators in e1
        if(label.ne.0)goto 2
23002 call xlpnd        ≠ end of loop
```

The sole purpose of xevery is to reset the second copy of cp, markcp, marksp, and flabel saved by xlpbeg (see Figure 6). The values of these variables saved by xlpbeg do not reflect the data accumulated by the evaluation of e1. If a next expression appears in e2, the failure label, system stack, and control stack must be restored to the state that they had immediately following the evaluation of e1. The second copy of this data saved by xlpbeg is used for this purpose and xevery simply records the current values of cp, markcp, marksp, and flabel after every activation of e1.

As mentioned in the previous section, however, xnext resets sp, which amounts to discarding partially computed results that may be required for computing alternatives of e1. The reason this action does not cause problems is that upon return from xnext, control is transferred to the statement labeled 23001 (see above), signal is set to 0, and xdrive is called. If e1 has more alternatives, xdrive resets sp from the current value of marksp, which was reset by xevery. Thus, resetting sp in xnext has no effect in every loops. A better technique would be to treat every loops differently from the other loop constructs. In particular, the duplicate copy of the data saved by xlpbeg (see Figure 6) is needed only for every loops, and most of the complications to break and next are caused by the generative aspects of every.

#### 4. Programming Conventions and Peculiarities

There are a number of less-than-obvious programming conventions and peculiarities in the implementation of Icon that deserve discussion. Most of these are due to the use of Fortran as an implementation language.

##### 4.1 Stability

All routines in the implementation are classified as either stable or unstable. An unstable routine is one that has the potential of causing a reclamation in some region; a stable routine is one that can never cause a reclamation. A routine is unstable if it calls an unstable routine.

This convention is very important because failure to place pointers in tended locations prior to calling unstable routines leads to time- and data-dependent bugs that are very difficult to locate. Thus, the usual technique is to push local variables that contain pointers onto the system stack before calling an unstable routine and to pop them off upon return.

#### 4.2 Calling Unstable Routines

Actual arguments to Fortran subroutines and functions are passed by reference. This mechanism has induced a particular programming convention for calling unstable routines.

To illustrate the problem, consider the call

```
z = cat(mem(sp), mem(sp+2))
```

which appears to concatenate the two values at the top of the stack and assign the result to z. The problem is that if cat is unstable (assume it is), the value of sp may change midway during its execution due to a reclamation. If this occurs, the addresses of the actual arguments are no longer valid.

In implementations of Fortran that use call by reference for all arguments (e.g. CDC FTN [15]), references to the actual arguments after the reclamation access what appears to be junk. Some implementations of Fortran (e.g. DEC Fortran-10 [16]), use call by value-result for scalar arguments. In this kind of argument transmission, the value of the actual argument is fetched upon entry to the routine and stored in a local variable. Upon exit, the final value of the local variable is stored in the actual argument. After the reclamation in this case, not only do references to the actual argument access junk, but the assignment upon exit overwrites the wrong data in mem.

These problems are avoided by writing the above call as

```
x = mem(sp)
y = mem(sp+2)
z = cat(x, y)
```

and not using the values of x and y after the call to cat.

Similar comments apply to statements such as

```
call f(g(x), y)
```

where g(x) returns a pointer and f is unstable. In this case, the value of g(x) is stored in an untended temporary location. Note, however, that this statement is safe if f copies its arguments to tended locations upon entry; this "trick" is not used.

As a result of these problems, there are very few routines that have calling sequence like cat above. Most unstable routines do not take tended arguments as Fortran arguments, but use the system stack for the transmission of tended arguments and results.

### 4.3 The Stack

Since the stack grows backwards, the sequence to push x onto the stack is

```
sp = sp - 1
mem(sp) = x
```

This code does not check for overflow, however. Overflow has occurred when the stack pointer (sp) equals the heap free pointer (hepfrp). Thus, the correct sequence to push x is

```
if (sp == hepfrp)
    ... overflow ...
sp = sp - 1
mem(sp) = x
```

This sequence is tedious, and is avoided by the use of stkchk. The call stkchk(n) insures that there are at least n cells of available stack space. Thus, to push several values onto the stack, stkchk is called to insure enough room followed by code to push each value. For example, the following code pushes x and y onto the stack as junk.

```
call stkchk(4)
mem(sp-1) = -1
mem(sp-2) = 2
mem(sp-3) = x
mem(sp-4) = y
sp = sp - 4
```

The pushes are written in this fashion to avoid repeated decrements of sp. In a reference like mem(sp-3), most Fortran compilers will absorb the -3 into the address portion of the instruction. As a result, the above sequence usually generates good code using the value of sp (in a register) as an offset from 4 different addresses.

As shown in Appendix C, there are no calls to stkchk in the generated code. The translator estimates the amount of stack space required to execute a procedure, and stkchk is called during procedure invocation to insure sufficient stack space.

### Acknowledgements

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## Appendix A. Format of the Generated Icon Program

The following code is an example of the overall structure of the Fortran code generated by the translator.

```
1      subroutine icon
2      common /cmain/signal,label,flabel,line
3      integer signal,label,flabel,line
4      integer xcmp,xlcmp,xncmp,xcomp
5      integer s(NS+1), p(NP+1), g(NG+1), i(NI+1), l(NL+1)
6      real r(NR+1)
7      data s/NS, .../
8      data g/NG, .../
9      data p/NP, .../
10     data i/NI, .../
11     data l/NL, .../
12     data r/NR, .../
13     call sinit(s,g,p,i,r,l)
14     call xglobl(1)           ≠ 1 = main procedure global
15     call xderef             ≠ get the procedure value
16     call xcproc             ≠ convert to procedure and go to it
17     call xinвок((NP+1)*MAXLABELS,0)
18     goto 23001
19     1 call pl
20     goto 23001
21     .
22     .
23     .
24     i call pi
25     goto 23001
26     .
27     .
28     .
29     NP call pNP
30     goto 23001
31     NP+1 return
32 23001 kk=label/MAXLABELS
33     goto (1,2,...,NP),kk
34     call syserr(29hicon: illegal internal label.)
35     return
36     end
37     .
38     .
39     .
40     subroutine pi           ≠ one for each Icon procedure
41     common /cmain/signal,label,flabel,line
42     integer signal,label,flabel,line
43     integer xcmp,xlcmp,xncmp,xcomp
44     goto 2
45     3 continue
46     .
47     .           ≠ generated code (see Appendix B)
48     .
49     1 label=flabel
```

```

50      2 if(label/MAXLABELS .ne. i)return
51      kk=mod(label,MAXLABEL)
52      goto(1,2,3,....,n),kk
53      call syserr(27hpi: illegal internal label.)
54      return
55      end

```

The numbers in the following explanation refer to line numbers in the above program skeleton.

2-3, 41-42: The labeled common cmain contains the global identifiers referenced by the compiled code; it serves to communicate current status information to and from the runtime system. Signal is the current value of the signal, label is used for transfer of control much like a location counter, flabel contains the label to which control is transferred upon failure, and line is the line number in the source program of the current focus of execution.

4,43: These routines are called for comparisons; they return integers.

5-12: These arrays contain initialization data. The general format is that the first element contains a count of the number of data elements that follow. The array s contains the characters appearing in string literals and identifiers. Each string is terminated by an EOS character. The array p contains control data for each procedure; g contains global identifier names as indices into s; i contains literal integers; l contains literal strings as indices into s; and r contains literal reals.

13: Sinit initializes storage and copies the data appearing in s, g, p, i, r, and l into the appropriate Icon storage regions.

14-18: This is code to invoke the main procedure much in the same way that other procedures are invoked. The return point, labeled NP+1 where NP is the number of procedures, causes a return to the Fortran main program, which terminates execution.

19-23: Labels that may be targets for transfer of control are composed of two parts, a procedure number p and an internal (Fortran) label i. A label is represented by p\*MAXLABELS+i. Whenever control leaves a procedure, it returns to the subroutine icon, which serves to transfer control to another procedure. The code in this section accomplishes this kind of transfer.

40,44-45: Each Icon procedure is translated into a Fortran subroutine named pi, where i is the procedure number. The procedure entry point is in line 44, but execution begins by transferring to the local "switch yard" in case the procedure was suspended.

46-48: Generated code for the procedures as described in Appendix B.

49-52: This is the local goto "switch yard" that is used to transfer control. The label l causes the current value of flabel to be used; transfer of control upon failure is effected by transfer to this label. If the target is not in the current procedure, a return to subroutine icon is made, otherwise control is transferred as indicated by the local label portion of the value of label.

With two exceptions, the Fortran code generated by the Icon translator conforms to the Fortran standard as embodied in the PFORT verifier [17].

The most serious exception is in the data statements illustrated in lines 7-12 above. It is assumed that arrays can be initialized by data statements of the form

```
data a /value of a(1), value of a(2), ..., value of a(N)/
```

or, if the array is large, by data statements of the form

```
data (a(k),k=1,100) /value of a(1), ..., value of a(100)/  
data (a(k),k=101,200) /value of a(101), ..., value of a(200)/  
data (a(k),k=201,N) /value of a(201), ..., value of a(N)/
```

The ANSI standard form requires explicit specification of each element of the array, i.e.

```
data a(1) /value of a(1)/  
data a(2) /value of a(2)/  
...  
data a(N) /value of a(N)/
```

If the form of the data statements causes problems, it can be changed by modifying the translator routine `outds`, which is called to output most data statements. Exceptions are the array `r` (see line 12 above), which is output in `outhdr`, and field offset arrays, which are described below.

The second exception concerns the use of block data subprograms. If records are used in an Icon program, arrays containing field offsets are generated and placed the labeled common `cflds`. A block data subprogram is generated that initializes these arrays. The problem is that, in this case, there are two block data subprograms -- the one that initializes `cflds` and one that initializes other runtime data used by every Icon program. Having more than one block data subprogram is contrary to the ANSI standard and may cause problems. If so, the offset arrays can be made local to each Fortran procedure (corresponding to each Icon procedure) by modifying the translator routine `outfld`. This routine is called to output the common statement in each subroutine and may be modified to output the data statements in place of the common statement. Note that the arrays are output directly by `outfld`; `outds` is not called. Thus, if the form of data statement mentioned above causes problems, `outfld` will need to be modified.

## Appendix B. A Grammar for Icon

The following grammar for Icon is left-factored and has no left-recursive productions. The code segments in the parser for each non-terminal are derived from the productions in this grammar. Language constructs processed by pass one, such as record and global declarations, are not shown.

```
PROC    --> procedure INIT SLIST
INIT    --> initial DEXP
        | eps
SLIST   --> DEXP SLISTP
SLISTP  --> ';' DEXP SLISTP
        | <newline> DEXP SLISTP
        | eps
DEXP    --> EXP
EXP     --> AND
        | eps
AND     --> ASSIGN ANDP
ANDP    --> '&' ASSIGN ANDP
        | eps
ASSIGN  --> TOBY ATYP
ATYP    --> ":@" ASSIGN
        | "::-" ASSIGN
        | "<-" ASSIGN
        | "<->" ASSIGN
        | eps
TOBY    --> OR TOBYP
TOBYP   --> to OR BY TOBYP
        | eps
BY      --> by OR
        | eps
OR      --> RELOP ORP
ORP     --> '|' RELOP ORP
        | eps
RELOP   --> CONCAT RELOPP
RELOPP  --> '=' CONCAT RELOPP
        | "~=" CONCAT RELOPP
        | '<' CONCAT RELOPP
        | "<=" CONCAT RELOPP
        | '>' CONCAT RELOPP
        | ">=" CONCAT RELOPP
        | "==" CONCAT RELOPP
        | "~==" CONCAT RELOPP
        | "===" CONCAT RELOPP
        | "~===" CONCAT RELOPP
        | eps
CONCAT  --> ADDOP CONCATP
CONCATP --> "||" ADDOP CONCATP
        | eps
ADDOP   --> MULOP ADDOPP
ADDOPP  --> '+' MULOP ADDOPP
        | '-' MULOP ADDOPP
        | "++" MULOP ADDOPP
        | "--" MULOP ADDOPP
```

```

      | eps
MULOP  --> EXPOP MULOPP
MULOPP --> '*' EXPOP MULOPP
      | '/' EXPOP MULOPP
      | "*" EXPOP MULOPP
EXPOP  --> SUFFIX ETYP
ETYP   --> '^' EXPOP
      | eps
SUFFIX --> PREFIX SUFFIXP
SUFFIXP --> '+' SUFFIXP
      | '-' SUFFIXP
      | fails SUFFIXP
      | eps
PREFIX --> '~' PREFIX
      | '+' PREFIX
      | '-' PREFIX
      | '=' PREFIX
      | '!' PREFIX
      | PRIME
PRIME  --> '&' KEYWORD PRIMEP
      | LOCAL PRIMEP
      | GLOBAL PRIMEP
      | BUILTIN '(' ELIST ')' PRIMEP
      | RNAME '(' ELIST ')' PRIMEP
      | LITERAL PRIMEP
      | '(' EXP ')' PRIMEP
      | '<' ELIST '>' PRIMEP
      | '{' SLIST '}' PRIMEP
      | if DEXP then DEXP ELSEX PRIMEP
      | while DEXP do DEXP PRIMEP
      | until DEXP do DEXP PRIMEP
      | every EXP DOX PRIMEP
      | repeat DEXP PRIMEP
      | fail PRIMEP
      | succeed RETX PRIMEP
      | return RETX PRIMEP
      | suspend RETX PRIMEP
      | break PRIMEP
      | next PRIMEP
      | stack '(' EXP ')' PRIMEP
      | table '(' EXP ')' PRIMEP
      | list '(' PROTO ')' AINIT PRIMEP
      | scan DEXP using DEXP PRIMEP
      | case DEXP of '{' CLIST '}' PRIMEP
PRIMEP --> '(' ELIST ')' PRIMEP
      | '{' EXP '}' PRIMEP
      | '.' FNAME PRIMEP
      | eps
ELSEX  --> else DEXP
      | eps
DOX    --> do DEXP
      | eps
RETX   --> DEXP
      | eps

```

```

ELIST  --> EXP ELISTP
ELISTP --> ',' EXP ELISTP
      | eps
LITERAL --> INT
      | FLOAT
      | STRING
ALIST  --> LOCAL ALISTP
ALISTP --> ',' LOCAL ALISTP
      | eps
PROTO  --> DEXP UBX
      | eps
UBX    --> ':' DEXP
      | eps
AINIT  --> initial DEXP
      | eps
CLIST  --> CELEM CLISTP
CLISTP --> ';' CELEM CLISTP
      | <newline> CELEM CLISTP
      | eps
CELEM  --> default ':' DEXP
      | LLIST ':' DEXP
LLIST  --> LITERAL LLISTP
LLISTP --> ',' LITERAL LLISTP
      | eps

```

## Appendix C. Syntax and Corresponding Fortran Code

This appendix gives an informal BNF-like description of Icon and the form of the corresponding generated code. The notation is as follows: curly braces denote required constructs, square brackets denote optional constructs, and ellipses following a group denote repetition. No attempt has been made to show relative precedence in expressions. A nonterminal appearing in the code denotes its own generated code.

A <procedure> is

procedure <ident> [ <header-decl> ] <dexpl>... end

L1	continue	≠ generate entry label
	call xreset(L2)	≠ reset if <u>initial</u>
	<dexp0>	≠ evaluate initial clause
L2	continue	≠ secondary entry point
	<dexpl>	≠ generate procedure body
	call xpop	≠ pop final value
	call xpnnull	≠ generate default return
	call xretrn	≠ and return
	goto JUMP	

A <dexp> is

if <dexp> then <dexpl> else <dexp2>

	<dexp>	≠ evaluate boolean
	call xpop	≠ throw away value
	if (signal .eq. 0) goto F1	≠ jump if <dexp> failed
	<dexpl>	≠ evaluate the statment
	goto F2	≠ skip second expression
F1	signal = 1	≠ reset signal to success
	<dexp2>	≠ evaluate second expression
F2	continue	
	if (signal .eq. 0) goto FAIL	≠ check failure if necessary

while <dexp> do <dexp>

		≠ F1 = next, F2 = break lab
	call xlpbeg	≠ establish loop beginning
F1	<dexp>	≠ evaluate boolean
	call xpop	≠ discard its value
	if (signal .eq. 0) goto F2	≠ skip out on failure
	<dexp>	≠ evaluate the expression
	call xpop	≠ discard its value
	goto F1	≠ and loop
F2	call xlpnd	≠ close down loop



until <dexp> do <dexp>

	call xlpbeg	≠ establish loop beginning
F1	<dexp>	≠ evaluate boolean
	call xpop	≠ discard its value
	if (signal .eq. 1) goto F2	≠ skip out on success
	signal = 1	≠ remove failure signal
	<dexp>	≠ evaluate the expression
	call xpop	≠ discard its value
	goto F1	≠ and loop
F2	call xlpend	≠ close down loop

every <exp>

	call xmark(L1)	≠ mark stacks; failure label
	<exp>	≠ evaluate expression
	call xpop	≠ throw away value
	signal = 0	≠ force failure
L1	call xdrive	≠ iterate
	if (label .ne. 0) goto JUMP	≠ jump if more alternatives
	signal = 1	≠ loop must succeed

every <exp> do <dexp>

	call xlpbeg	≠ establish loop beginning
	call xmark(L1)	≠ mark stacks; failure label
	<exp>	≠ evaluate the generator
	call xpop	≠ throw away value
	call xevery	≠ mark c stack data
	<dexp>	≠ evaluate the expression
	call xpop	≠ throw away value
F1	continue	≠ next label
	signal = 0	≠ force failure
L1	call xdrive	≠ iterate
	if (label .ne. 0) goto JUMP	≠ jump if more alternatives
F2	call xlpend	≠ close down loop

repeat <dexp>

	call xlpbeg	≠ establish loop beginning
F1	<dexp>	≠ evaluate expression
	call xpop	≠ discard value
	if (signal .eq. 1) goto F1	≠ loop on success
F2	call xlpend	≠ close down loop

scan <dexp1> using <dexp2>

<dexp1>	≠ evaluate subject
if (signal .eq. 0) goto FAIL	≠ abandon on failure
call xderef	≠ dereference if needed
call xcstrg	≠ convert to string if needed
call xscan1	≠ setup for scanning
<dexp2>	≠ do scanning
call xscan2	≠ restore &subject and &pos
if (signal .eq. 0) goto FAIL	≠ check for failure

case <dexp0> of { [ { <lit1>, }... | default : <dexpj> ]... }

<dexp0>	≠ evaluate case expression
call xecase	≠ error if <dexp0> fails
if (xcomp(n1,t1).ne.0) goto F2	≠ n1 = literal, t1 = type
call xpop	≠ discard case expression value
<dexp1>	≠ evaluate expression for lit1
goto F1	≠ skip remainder of case
F2 if (xcomp(n2,t2).ne.0 .and. xcomp(n3,t3).ne.0)) goto F3	≠ check next set of literals
call xpop	≠ discard case expression value
<dexp2>	≠ evaluate expression for lit2
goto F1	≠ skip remainder of case
.	
.	
.	
Fn call xpop	≠ discard case expr value
<default expression>	≠ evaluate <u>default</u>
F1 continue	

fail

call xpnnull	≠ push &null
signal = 0	≠ force failure
call xretrn	≠ return &null,failure
goto JUMP	≠ computed branch

succeed

call xpnnull	≠ push &null
signal = 1	≠ force success
call xretrn	≠ return &null,succeed
goto JUMP	≠ computed branch

succeed <dexp>

<dexp>	≠ evaluate return value
signal = 1	≠ force success
call xretrn	≠ return value,success
goto JUMP	≠ computed branch

return

call xpnull	≠ push &null
signal = 1	≠ force success
call xretrn	≠ return &null,success
goto JUMP	≠ computed branch

return <dexp>

<dexp>	≠ evaluate return value
call xretrn	≠ return value,signal
goto JUMP	≠ computed branch

suspend

call xpnull	≠ push &null
L1 call xsusp(L1)	≠ set up for suspend &null
if (label .ne. 0) goto JUMP	≠ jump if really suspending
signal = 1	≠ insure success signal

suspend <exp>

call xmark(L1)	≠ mark stacks
<exp>	≠ evaluate the argument
L2 call xsusp(L2)	≠ suspend argument
if (label .ne. 0) goto JUMP	≠ jump if really suspending
L1 call xdrive	≠ extract alternative value
if (label .ne. 0) goto JUMP	≠ jump if we have any
signal = 1	≠ force success

break

goto F2	≠ break from loop (to xlpnd)
---------	------------------------------

next

call xnext	≠ adjust stack heights
goto F1	≠ iterate

< [ <exp> , ]... >

<exp1>	≠ compute first element
call xderef	≠ dereference if necessary
<exp2>	≠ compute second element
call xderef	≠ dereference if necessary
.	
.	
.	
call xllist(n)	≠ n = number of elements

<dexp>

call xmark(L1)	≠ mark stacks; failure label
<exp>	≠ evaluate expression
L1 call xdrive	≠ drive expression to success
if (label .ne. 0) goto JUMP	≠ jump if more alternatives

<exp> is

For built-in prefix, suffix, and infix operators and built-in functions, the code sequences given below are the maximum that may be required. In general, the label L1 (both in label position and as argument) is supplied only if the operation is a generator. The signal test and branch to FAIL is eliminated for unconditional operations (note that all generators are conditional). Dereferencing and conversion code is also optional. Dereferencing is required whenever a variable (either natural or computed, including values returned by defined procedures) is given when a value is required. A call to a conversion routine is required when an argument is of the wrong or unknown type. The conversion routines are

xcintg	convert to integer
xcstrg	convert to string
xcfile	convert to file
xcreal	convert to real
xccset	convert to character set
xcnumr	convert to numeric
xcproc	convert to procedure
xcrecd	convert to record

<prefix> <exp>

<exp>	≠ evaluate expression
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
L1 call "opcode"(L1)	≠ "opcode" is prefix name
if (signal .eq. 0) goto FAIL	≠ check failure if needed

<exp> <suffix>

<exp>	≠ evaluate expression
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
L1 call "opcode"(L1)	≠ "opcode" is suffix name
if (signal .eq. 0) goto FAIL	≠ check failure if needed

<expl> <infix> <exp2>

<expl>	≠ evaluate first operand
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
<exp2>	≠ evaluate second operand
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
L1 call "opcode"(L1)	≠ "opcode" is infix name
if (signal .eq. 0) goto FAIL	≠ check failure if needed

The code for numeric and lexical comparisons uses two functions, xncmp and xlcmp. These functions compare the top two values on the stack and return -1, 0, or +1, if the top value is less than, equal to, or greater than the value below it on the stack. This result is then compared to zero using one of the Fortran comparisons (e.g., .le.).

<expl> <relop> <exp2>

<expl>	≠ evaluate first argument
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
<exp2>	≠ evaluate second operand
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
if (x?cmp(junk).??0) goto FAIL	≠ check relation

<ident> ( [ <exp> , ]... )

<expl>	≠ built-in procedure
<expl>	≠ evaluate first argument
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
<exp2>	≠ evaluate second argument
call xderef	≠ dereference arg if needed
call xc????	≠ convert arg if needed
.	
.	
.	
L1 call "opcode"(L1)	≠ pass correct number of args
if (signal .eq. 0) goto FAIL	≠ check failure

<exp1> ( [ <exp2> , ]... )

<exp1>	≠ procedure call
call xderef	≠ evaluate proc name
call xcproc	≠ dereference proc
<exp2>	≠ convert to procedure
call xderef	≠ evaluate first arg
<exp3>	≠ dereference arg if needed
call xderef	≠ evaluate second arg
.	≠ dereference arg if needed
.	
.	
call xinvok(L1,n)	≠ n = number of args
goto JUMP	≠ jump to the procedure
L1 if (signal .eq. 0) goto FAIL	≠ check failure

{ [ <dexp> ]... }

<dexp>	≠ generate expression code
call xpop	≠ discard value (except last)

<exp0> [ <exp1> ]

<exp0>	≠ evaluate list or string
<exp1>	≠ evaluate subscript
call xacc	≠ access list
if (signal .eq. 0) goto FAIL	≠ check failure

<exp1> & <exp2>

<exp1>	≠ evaluate left argument
call xpop	≠ throw away value
<exp2>	≠ evaluate second argument

<exp1> | <exp2>

L1 if (signal .eq. 0) goto F1	≠ F1 = alternate label
call save(L1)	≠ L1 = reactivation label
<exp1>	≠ evaluate first expression
goto F2	≠ skip second expression
F1 signal = 1	≠ reset for success
<exp2>	≠ evaluate second expression
F2 continue	

<exp1> to <exp2>

<exp1>	≠ evaluate from expression
call xderef	≠ dereference arg if needed
call xcintg	≠ convert to integer
<exp2>	≠ evaluate to expression
call xderef	≠ dereference arg if needed
call xcintg	≠ convert to integer
L1 call xto(L1)	≠ generate values
if (signal .eq. 0) goto FAIL	≠ check failure

<exp1> to <exp2> by <exp3>

<exp1>	≠ evaluate from expression
call xderef	≠ dereference arg if needed
call xcintg	≠ convert to integer
<exp2>	≠ evaluate to expression
call xderef	≠ dereference arg if needed
call xcintg	≠ convert to integer
<exp3>	≠ evaluate by expression
call xderef	≠ dereference arg if needed
call xcintg	≠ convert to integer
L1 call xtoby(L1)	≠ generate values
if (signal .eq. 0) goto FAIL	≠ check failure

<dexp> fails

<dexp>	≠ evaluate expression
signal = iabs(signal - 1)	≠ invert signal
if (signal .eq. 0) goto FAIL	≠ check failure

list ( [ <exp1> : ] <expu> ) [ initial <exp> ]

<exp1>	≠ evaluate lower bound
<expu>	≠ evaluate upper bound
<exp>	≠ evaluate initial value
call xmarry(0 or 1)	≠ make list

table ( <exp> )

<exp>	≠ evaluate table size
call xmtabl	≠ make the table

stack ( <exp> )

<exp>	≠ evaluate stack size
call xmstak	≠ make the stack

<record name> ( <expl>, ..., <expm> )

<expl>	≠ evaluate first field
.	
.	
.	
<expm>	≠ evaluate last field
call xmrecd(t,k,m,n)	≠ make record, t = record type, ≠ k = record name, ≠ n = number of fields

<exp> . <identifier>

<exp>	≠ evaluate record expression
call xfacc(fi)	≠ fi = field offset array

<integer>

call xpintg(n)	≠ n = integer offset
----------------	----------------------

<real>

call xpreal(n)	≠ n = real offset
----------------	-------------------

<string>

call xpstrg(n)	≠ n = string offset
----------------	---------------------

<local identifier>

call xlocal(n)	≠ n = identifier offset
----------------	-------------------------

<global identifier>

call xglobl(n)	≠ n = identifier offset
----------------	-------------------------

A <body> is

[ <decl> ]... [ <dexp> ]...

A <decl> is

local [ <ident> , ]...



A <literal> is

```
" string not containing double quote "  
' string not containing single quote '  
{ digit }...  
{ digit }... . [ digit ]...
```

A <ident> is

```
{ alpha } [ alpha | digit | underscore { alpha | digit }... ]...
```

## Appendix D. Built-in Operators, Functions, and Keywords

This appendix contains a list of the Icon built-in operations. The following information is included with each operation.

argument information  
type of the returned result  
failure indication  
generator indication

The argument information is either the datatype expected or the default if no argument is given (from which the type may be deduced). Note that all generators may fail.

### C.1 Built-in Operators

+ ( -- convert to numeric +any -> numeric	call xnumr	
- ( -- negate -numeric -> numeric	call xneg	
= ( -- tab over matched string =string -> string	call xtabm	generator
~ ( -- negate character set ~cset -> cset	call xnotc	
! ( -- access structure !any -> variable	call xbang	generator
) + -- increment	call xdupl call xderef call xnumr call xpone call xadd	
variable + -> variable		
) - -- decrement	call xdupl call xderef call xnumr call xpone call xsub	
variable - -> variable		

)^( -- power numeric ^ numeric -> numeric	call xpower	
)*( -- multiplication numeric * numeric -> numeric	call xmul	
)+( -- addition numeric + numeric -> numeric	call xadd	
)-( -- subtraction numeric - numeric -> numeric	call xsub	
)/( -- division numeric / numeric -> numeric	call xdiv	
** ( -- character set union cset ** cset -> cset	call xunion	
-- ( -- character set difference cset -- cset -> cset	call xdiff	
:= ( -- assignment variable := any -> any	call xasg	may fail
:=: ( -- value swap variable :=: variable -> any	call xswap	may fail
< ( -- .lt. predicate numeric < numeric -> numeric	xncmp(junk)	
<= ( -- .le. predicate numeric <= numeric -> numeric	xncmp(junk)	
= ( -- .eq. predicate numeric = numeric -> numeric	xncmp(junk)	
== ( -- .eq. string string == string -> string	xlcmp(junk)	

)>( -- .gt. predicate numeric > numeric -> numeric	xncmp(junk)	
)>=( -- .ge. predicate numeric >= numeric -> numeric	xncmp(junk)	
)  ( -- concat string    string -> string	call xcat	
)~=( -- .ne. predicate numeric ~= numeric -> numeric	xlcmp(junk)	
)~==( -- .ne. string string ~= string -> string	xlcmp(junk)	
)===( -- .eq. structure any === any -> any	xcmp(junk)	
)~===( -- .ne. structure any ~=== any -> any	xcmp(junk)	
)<-( -- reversible assignment variable <- any -> any	call xrasg	generator
)<->( -- reversible swap variable <-> variable -> any	call xrswap	generator

## C.2 Built-in Functions

any -- match character any(cset:""",string:&subject, integer:&pos or 1,integer:0) -> integer	call xany	may fail
bal -- match balanced string bal(cset:&ascii,cset:"(",cset:""), string:&subject,integer:&pos or 1,integer:0) -> integer	call xbal	generator
center -- center text in string center(string:""",integer:0,string:" ") -> string	call xcent	

close -- close object	call xclose	
close(any:file,table,or array) -> argument		
copy -- copy structure	call xcopy	
copy(any:null) -> argument		
cset -- convert to character set	call xcset	
cset(any:null) -> cset		
display -- display symbol table	call xdisp	
display(integer:1) -> null		
find -- find string	call xfind	generator
find(string:****,string:&subject, integer:&pos or 1,integer:0) -> integer		
image -- convert to string image	call ximage	
image(any:null) -> string		
integer -- convert to integer	call xnumr	may fail
integer(any:null) -> integer	if (signal .eq. 0) go to FAIL	
	call xintg	
left -- left justify in string	call xleft	
left(string:****,integer:0,string:" ") -> string		
lge -- lexical >=	call xlge	may fail
lge(string:****,string:****) -> string		
lgt -- lexical >	call xlgt	may fail
lgt(string:****,string:****) -> string		
lle -- lexical <=	xlcmp(junk)	may fail
lle(string:****,string:****) -> string		
llt -- lexical <	xlcmp(junk)	may fail
llt(string:****,string:****) -> string		

many -- span characters                    call xmany            may fail  
many(cset: "", string:&subject, integer:&pos or 1,  
                                 integer:0) -> integer

map -- translate characters                call xmap  
map(string: "", string: "", string: "") -> string

match -- match string                    call xmatch           may fail  
match(string: "", string:&subject, integer:&pos or 1,  
                                 integer:0) -> integer

mod -- get remainder                    call xmod  
mod(numeric:0, numeric:0) -> numeric

move -- move in &subject                call xmove            generator  
move(integer:0) -> variable

null -- check for null                  call xnull            may fail  
null(any:null) -> null

numeric -- convert to numeric            call xnumr            may fail  
numeric(any:null) -> numeric

open -- open object                    call xopen            may fail  
open(any:file, table, or array, string: "") -> argument

pop -- pop off stack                    call xpops            may fail  
pop(stack) -> any

pos -- convert to cursor position        call xpos            may fail  
pos(integer:0, string:&subject) -> integer

push -- push onto stack                call xpushs  
push(stack, any) -> any

random -- compute random integer        call xrand  
random(integer:1) -> integer

read -- read line                      call xread            may fail  
read(file:&input) -> string

reads -- read string	call xsread	may fail
reads(file:&input,integer:1) -> string		
real -- convert to real	call xcreal	may fail
real(any:null) -> real		
repl -- replicate string	call xrepl	
repl(string: "",integer:0) -> string		
reverse -- reverse string	call xrev	
reverse(string: "") -> string		
right -- right justify in string	call xright	
right(string: "",integer:0,string: " ") -> string		
section -- get section	call xsect	may fail
section(variable:&subject,integer:&pos or 1,integer:0) -> variable		
size -- size of an object	call xsize	
size(any:string or list) -> integer		
sort -- sort array or table	call xsort	may fail
sort(any:null,integer:1) -> argument		
stop -- stop execution	call xstop(n)	
stop(any list) -> null (n = number of arguments)		
string -- convert to string	call xstrg	may fail
string(any:null) -> string		
substr -- get substring	call xsubst	may fail
substr(variable:null,integer:0,integer:0) -> variable		
tab -- tab through &subject	call xtab	generator
tab(integer:0) -> variable		
top -- get stack top	call xtops	may fail
top(stack) -> variable		

trim -- trim string	call xtrim	
trim(string:""",cset:" ") -> string		
type -- datatype of argument	call xtype	
type(any:null) -> string		
upto -- break to character set	call xupto	generator
upto(cset:""",string:&subject, integer:&pos or 1,integer:0) -> integer		
write -- write line	call xwrite(n)	
write(any list) -> string	(n = number of arguments)	
writes -- write string	call xswrit(n)	
writes(any list) -> string	(n = number of arguments)	
zz0, ..., zz9 -- system defined	call zz?(1,n)	generator
zz?(any list) -> variable	(n = number of arguments, 1 = reactivation label)	

### C.3 Keywords

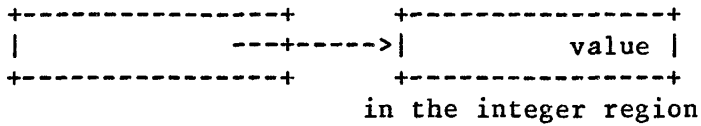
&ascii -> string	call xkeywd(KASCII)
&clock -> string	call xkeywd(KCLOCK)
&cset -> cset	call xkeywd(KCSET)
&date -> string	call xkeywd(KDATE)
&input -> file	call xkeywd(KINPUT)
&lcase -> string	call xkeywd(KLCASE)
&level -> integer	call xkeywd(KLEVEL)
&null -> null	call xkeywd(KNULL)
&output -> file	call xkeywd(KOUTPUT)
&pos -> variable:integer	call xkeywd(KPOS)
&random -> variable:integer	call xkeywd(KRANDOM)
&subject -> variable:string	call xkeywd(KSUBJECT)
&time -> integer	call xkeywd(KTIME)
&trace -> variable:integer	call xkeywd(KTRACE)
&ucase -> string	call xkeywd(KUCASE)



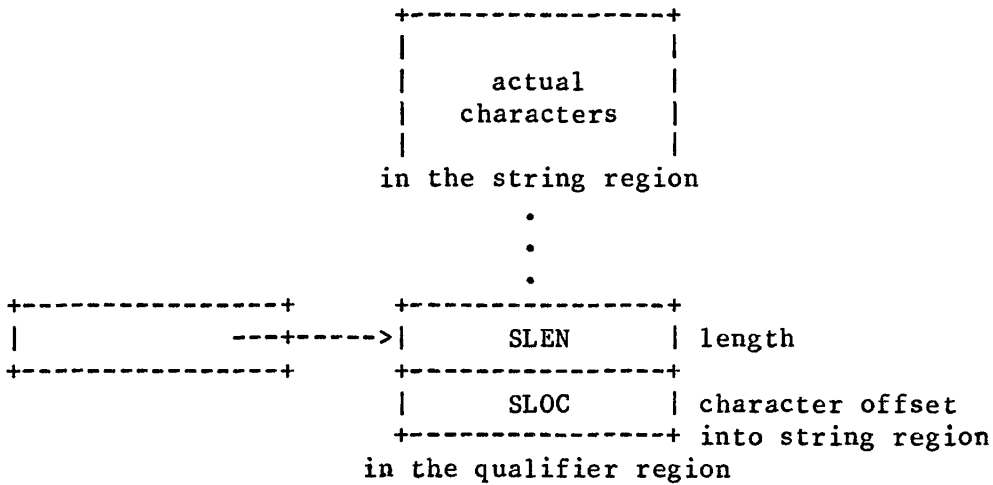
Appendix E. Pictorial Description of Icon Data Objects

The following figures depict the representation of Icon data objects. The symbols appearing in the figures correspond to the names used in the implementation. For types whose exact representation is machine dependent (such as csets), the DEC-10 representation is shown.

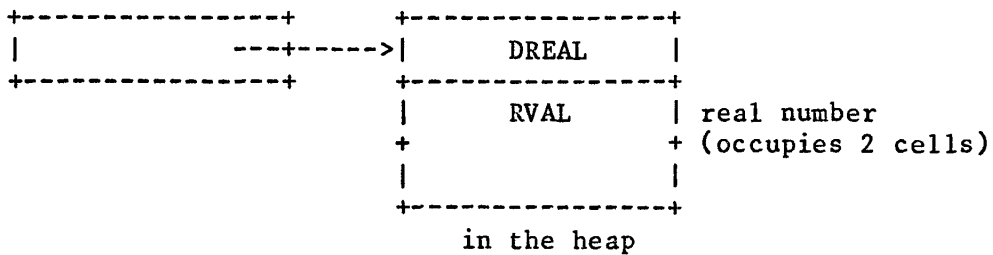
Integers (DINTG = 1)



Strings (DSTRG = 2)



Reals (DREAL = 3)



Character Sets (DCSET = 4)

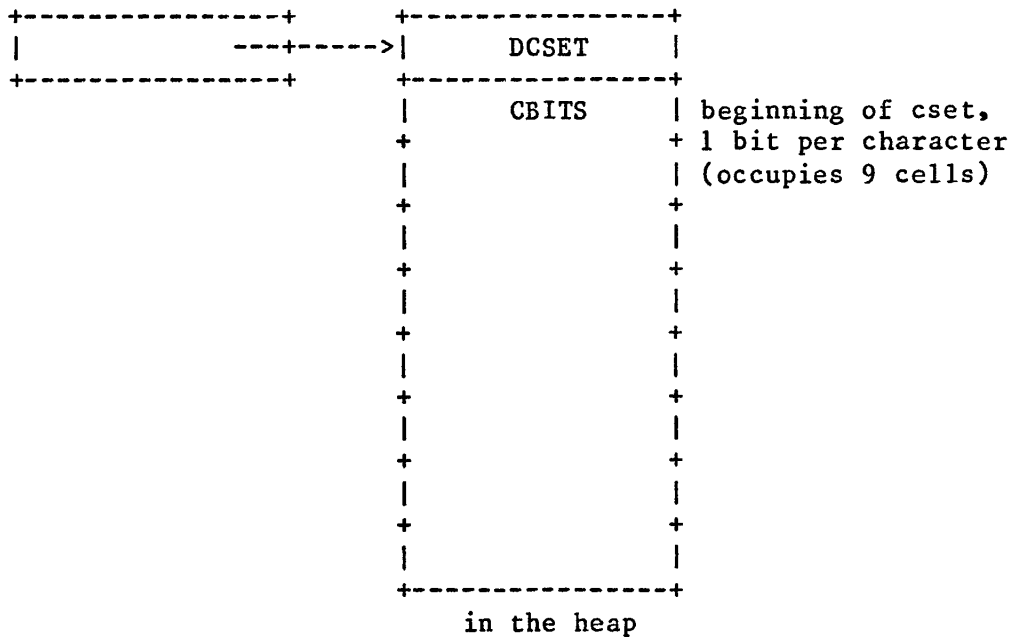
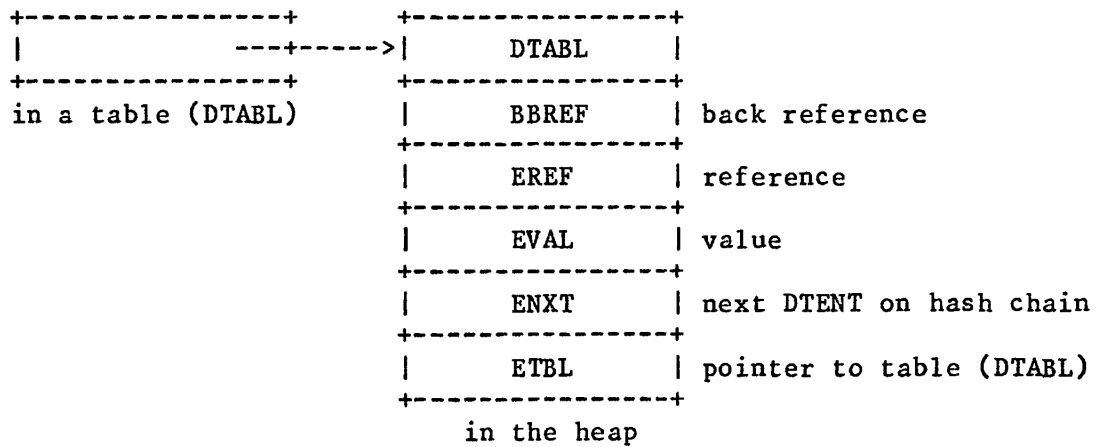


Table Elements (DTENT = 5, see DTABL)



Tables (DTABL = 6)

-----+	-----+	
	---+---->	DTABL
-----+	-----+	
		BBREF   back reference
		-----+
		TSIZE   size of this block
		-----+
		TREFT   type of reference field
		-----+
		TVALT   type of value field
		-----+
		TNMAX   maximum size of table
		-----+
		TNSIZ   current size of table
		-----+
		TBUCK   hash bucket[1]
		-----+
		hash bucket[2]
		-----+
		---+----> table element block
		(DTENT)
		•
		•
		•
		-----+
		hash bucket[n]
		-----+

in the heap

Lists (l-originated, non-expandable; DLIST = 7)

-----+	-----+	
	---+---->	DLIST
-----+	-----+	
		BBREF   back reference
		-----+
		LSIZE   size of this block
		-----+
		LTYPE   type of list elements
		-----+
		LELMT   beginning of elements
		•
		•
		•
		-----+

in the heap

Lists (arbitrary origin, expandable; DARRY = 8)

-----+-----	-----+-----	
	---+--->	DARRY
-----+-----	-----+-----	
		BBREF   back reference
		ASIZE   size of this block
		ATYPE   type of list elements
		AINIT   initial value
		AOPEN   YES if list is opened
		ALBND   lower bound
		AUBND   upper bound
		AELMT   beginning of elements
		•
		•
		•
		-----+-----
		in the heap

File (DFILE = 9)

-----+-----	-----+-----	
	---+--->	DFILE
-----+-----	-----+-----	
		BBREF   back reference
		FINAM   internal (integer) name
		FSTAT   status (see below)
		FNAME   string name
		-----+-----

Status Codes (contents of FSTAT):

FCLOS	-1	file is closed
FREAD	0	file is opened for reading
FWRIT	1	file is opened for writing
FRDWR	2	file is opened for reading and writing

Utility block (DUTIL = 10, not a source-language type)

+-----+             ---+----->	+-----+ DUTIL	
+-----+ 	+-----+ USIZE	size of this block
	+-----+ UDATA	beginning of non-tended data
	+-----+ in the heap	

Procedures (DPROC = 11)

+-----+             ---+----->	+-----+ DPROC	
+-----+ 	+-----+ BBREF	back reference
	+-----+ PSIZE	size of this block
	+-----+ PENTRY	entry point (a label)
	+-----+ PSMAX	maximum stack size
	+-----+ PPARAMS	number of parameters
	+-----+ PLOCALS	number of locals
	+-----+ PSTATIC	number of static locals
	+-----+ PNAME	printable name of procedure
	+-----+ PIDENTS	printable names of locals
	+-----+ in the heap	

Universal Null (DNULL = 12)

+-----+             0 +	+-----+ 
----------------------------	-------------

Stack (DSTAK = 13)

-----+-----	-----+-----
-----+----->	DSTAK
-----+-----	-----+-----
	BBREF   back reference
	-----+-----
	SSIZE   size of this block
	-----+-----
	STYPE   type of stack elements
	-----+-----
	SNMAX   maximum size of stack
	-----+-----
	SSP   stack pointer (an offset)
	-----+-----
	SELMT   beginning of elements
	•
	•
	•
	-----+-----
	in the heap

Records (DRECD = 14)

-----+-----	-----+-----
-----+----->	DRECD
-----+-----	-----+-----
	BBREF   back reference
	-----+-----
	DSIZE   size of this block
	-----+-----
	DNAME   record name as literal index
	-----+-----
	DTYPE   type number
	-----+-----
	DFLDS   beginning of fields
	•
	•
	•
	-----+-----
	in the heap

Tended block (DBLOK = 15, not a source-language type)

