DYSTAL: nonnumeric applications of FORTRAN

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ABSTRACT

This paper presents an explanation of how FORTRAN was used to write a list-processing language, DYSTAL, which uses linear arrays rather than linked word lists. Three basic features are dynamic storage allocation, integer array names as pointers, and a seven-word head for each array.
INTRODUCTION

I was in the Psychology Department of the University of Connecticut when IBM set up a computation center at MIT for use by New England colleges and universities. I attended the first summer institute offered at MIT in 1956, believe, and struggled through the assembly language programming course. At the end of the session a young man, who I believe was Sheldon Best, got up and announced that they were working on an automatic programming system called FORTRAN. The following year when FORTRAN was made available, I attended a short course on it in Boston. As a research associate to the MIT Computation Center I began to work on statistical programs in FORTRAN, and since then it has been the only language in which I have programmed.

My encounter with nonnumeric programming came in 1963 when I attended a summer institute on the use of IPL-V for simulation at the Rand Corporation. The session was organized by Bert Green. I found that IPL-V provided dynamic storage allocation, list-processing operations, such as insertion and deletion, and list-structures and procedures for handling them which could not be normally performed in FORTRAN. On the other hand, data handling was almost nonexistent, input-output was difficult, and even a simple device like a checkerboard could not be easily represented by linked-word lists. Moves on a checkerboard could not be specified by incrementing two subscripts as one could in FORTRAN, but instead lists of possible moves were utilized. Furthermore, programs written in IPL-V were reputed to be slow, and I attributed this to the linked-word list which required sequential rather than direct access to the middle of a list.

LINKED-WORD LISTS VS. LINEAR ARRAYS

Before the institute was half over I decided to write a list-processing language using FORTRAN subroutines and functions. I was not aware of Gelernter's FLPL. Joseph Weizenbaum's SLIP had just been announced, and to me it appeared to be IPL-V operations written as a series of FORTRAN subprograms, with a few primitives written in machine language. I decided that in order to preserve many of FORTRAN's efficient features lists should not consist of linked words but a linear string of words. My task was to find ways of providing dynamic storage allocation at runtime, list-processing operations and creation and operation of arrays connected into tree structures. I was able to provide all of these using procedures written as FORTRAN functions. I then proceeded to add string-processing routines, sorting operations and statistical and matrix operations, aiming for a general purpose language. The first DYSTAL Manual was completed in 1956. After the 1967 IFIP Working Conference on Symbol Manipulation Languages, I decided to make arrays relocatable, using a directory to hold the names of arrays and allowing arrays to move to a disk file as room in memory was depleted. A manual incorporating this improvement was put together in 1970.

My approach was that of an amateur, unaware of the niceties of computer language design, doing what appeared to be necessary to achieve features which FORTRAN did not normally provide. Much of this would not even be of historical significance, since DYSTAL was not widely used. But some of it is pertinent to the present-day effort to provide a more general-purpose language via FORTRAN. The X3J3 FORTRAN Committee is discussing setting up a core FORTRAN and extensions into different application areas. It is my belief that the core should be relatively flexible to allow for a variety of extensions. I would like to point out how I was able to make use of FORTRAN IV to accomplish unFORTRAN-like operations, while integrating numeric and nonnumeric procedures.

ESSENTIAL FEATURES

Three features were important to my effort to provide list-processing and list-structuring operations in FORTRAN. The first was dynamic storage allocation. The second was the name of an array which was separate from its content. In FORTRAN a variable, whether subscripted or not, referred to its content or value. To create tree structures or to chain arrays it was necessary to be able to use names of arrays as pointers. This called for a new data type—array name—which was different from integer and real variables. The third feature was required to provide the flexibility inherent in linked-word lists. I found this in the five-word head, which I later increased to seven words. These features were not independent of one another. I began with dynamic storage allocation, which brought into play the need to keep track of the location of an array and its features.

DYNAMIC STORAGE ALLOCATION

To implement dynamic storage allocation of linear arrays a single storage area was created and from it all arrays were allocated at runtime. To accomplish this three variables were dimensioned a maximum amount and made equivalent to one another and stored in COMMON. Later a disk file was added when arrays were made relocatable:

\[
\text{DIMENSION LOT (5000), FLOT (5000), GLOT (5000) EQUIVALENCE (LOT, FLOT, GLOT) COMMON GLOT DEFINE FILE 4 (1000, 80, U, JFI)}
\]
The equivalencing of the three arrays made it possible to cut out any type of array from the same storage area and even to store different types of variables on the same array. The EQUIVALENCE statement therefore played a central role in providing a flexible dynamic allocation system. The use of COMMON allowed each function to have access to the entire dynamic storage area without need to enter LOT or FLOT as arguments each time. GLOT was placed in COMMON to fool the compiler into believing that LOT and FLOT in COMMON were not being modified by a FORTRAN function. This rigid requirement was encountered in Basic FORTRAN when working with the IBM 1130 computer, and I would deem that as overprotection of the user. He is better served by permissiveness to change values in COMMON as needed.

ARRAY NAME

It was the development of dynamic storage allocation that permitted and also required a name separate from the content of the array. It was necessary to keep track of the position within LOT or FLOT where the next array was to start. This location was returned and used as the name of the array. If LOCA was the name of an array, LOT (LOCA + 1) or FLOT (LOCA + 1) referred to the value of the first word of that array. Thus LOT and FLOT came to mean "the content of" a word at a given location within the dynamic storage area. In the meantime, it was possible to use LOCA as a pointer to the array and store it on other arrays, making possible chains of arrays or tree structures. Below is shown a simple tree structure with an array called NAME holding the names of three arrays, LSTA, LSTB, LSTC. These in turn hold character strings, which have been read into created arrays:

```plaintext
NAME: LSTA, LSTB, LSTC
LSTA: D, O, G
LSTB: C, A, T
LSTC: H, O, R, S, E
```

It was a great day when I realized that to create a tree structure it did not matter where the arrays were stored. All that was necessary was to be able to store array names on the same name array.

Arrays were later made relocatable and an array called MAP served as the directory.

LSTA = MAPL (3, 10)

created an array named LSTA for real numbers of length 10. The name of the array was then the location on the directory. The directory in turn held the current location of the array.

THE HEAD OF AN ARRAY

I learned the use of the attached head of an array from IPL-V. Instead of a limited amount of information, I stored the length of the array, the count of items stored on it, the mode of the array (1-7), the node to be used to store pointers in creating chains of arrays or alternatively as the row size of a matrix, an alphabetic identification, a reference count, and the directory address. The head was positioned just before the array itself so that it could be accessed by means of a zero or negative subscript. LOT (LOCA) referred to the array counter, LOT (LOCA-1) to its length and LOT (LOCA-2) to its mode—i.e. the data type stored on the array. To a considerable extent list-processing type of operations were performed with the aid of information stored in the head of an array. LOAD (WD, LSTA) could be used to store a word at the end of the line and the counter increased by one. ITEM (– 9, LSTA) was used to take off the last word on the list. If the capacity of the array was exceeded when using LOAD, the array was moved automatically to a new location and enlarged by 20 percent and the routine continued. Routines for insertion and deletion required that words be moved to make room or eliminate an empty position.

To create and operate list structures names of arrays were placed on arrays with the data type of 1 (names of arrays), which distinguished them from integer arrays with a data type of 2. This distinction was desirable in writing a routine to walk through the list structure. Each of the seven modes was associated with an input-output format so that it was possible to print out an array with the simple instruction IDUMP (LSTA) or to print out all of the arrays in dynamic storage with the instruction CALL KDUMP. Thus, when creating an array its mode and dimensions were declared numerically and retained in the head of each array. In matrix operations, such as matrix multiplication, it was not necessary to specify the row and column sizes, since these could be calculated from information in the head of the arrays involved. The head was made possible by implementation of dynamic storage allocation and by use of the EQUIVALENCE statement.

The role of EQUIVALENCE is crucial in adding the head to each array. The information in the head could be handled as integer variables using LOT. The head could be attached to any array, whether they held integer, real or literal words. In developing DYSTAL for the IBM 1130 using Basic FORTRAN, I managed to equivalence two-byte integers with four-byte real words. I did not get around to adding double-precision words as data types, but that could have been managed. The ability to equivalence different data types and the addition of a head to each array greatly contributed to relieving the programmer of many bookkeeping chores.

RECURSION

FORTRAN subroutines are not recursive—i.e. they are not allowed to call themselves. Recursive routines are desirable in symbolic manipulation of formulas and in tracing through list structures. Recursion can be simulated in DYSTAL using the approach used by IPL-V. Within a procedure dynamic storage allocation can be used to provide a pushdown stack to store intermediate information. The necessary operations can then be performed in reverse order using information in the pushdown stack. At the end of the procedure the pushdown stack can be erased. Here it is dynamic storage allocation which permits an unFORTRAN-like operation.
VIRTUAL MEMORY

Virtual memory, if it exists, is generally provided by the computer system rather than by a compiler for a particular language. For smaller machines, however, virtual memory is generally not available, and using FORTRAN to provide it greatly adds to the flexibility of writing and running large programs. The implementation of virtual memory required the setting up of a directory as an array to hold the current location of each array. This could be in memory or on a disk file. Three types of arrays were distinguished: permanent arrays, which remained in memory at the low end of the storage area, temporary arrays which were created at the upper end, and semi-permanent ones which began where the permanent ones ended. When the free space reached the end of the storage space, it was allowed to wrap around to the beginning of the semipermanent arrays. Thus it was possible to move whole arrays each time to the disk file without fragmenting the storage space. Virtual memory also neatly solved the problem of garbage collection, since it was possible to allow unwanted arrays to move to the disk file and remain there.

ACCESS TO ARRAY ELEMENTS

Creating a name of an array required adding its location to the subscript for LOT or FLOT. Making the arrays relocatable further complicated the problem of access. When an array was created its name was saved in a FORTRAN variable or placed on an array:

\[ LSTA = MAPL (3, 10) \]

To get its location, the function LOCAL was called:

\[ LOCA = LOCAL (LSTA) \]

LOCA could then be used in the subscript of LOT to access the Ith element of LSTA: LOT (LOCA + I).

Retrieval was made simpler, but not efficient, by using retrieval functions ITEM (I, LSTA) and FITEM (I, LSTA). For storage the function IPUT (X, I, LSTA) was developed. Here X is the word to be stored in the Ith position of LSTA. FORTRAN, in spite of its rule that real and dummy arguments have to agree in number, order and type, allowed me to use IPUT for storing either integers or real words. There were further complications when arrays were made relocatable, since it was necessary to insure that accessing one array, which might be on the disk file, did not kick out another one that was needed in the same part of the program. One solution was to create such arrays early and declare them to be permanent. The other way to clear sufficient free space to make sure that there was sufficient free space for the required arrays. A routine called ICHEK (LSTA, LSTB, LOCA, LOCB) brings into memory LSTA and LSTB and provides their locations. Such procedures were most helpful at the beginning of subroutines to insure that both were in memory at the same time.

My general approach was to write frequently-used subprograms as efficiently as possible by subscripting LOT and FLOT. Retrieval functions, on the other hand, were used initially to write application programs. There was discussion fairly early in the game of the desirability of a precompiler which would take the less efficient functions and replace them with direct subscripts.

STRING PROCESSING

DYSTAL’s string processing operations could be applied to arrays of single characters or to words. It was hampered by the lack of literal constants, and it generally had to be assumed that character strings were read into dynamically-created arrays. It was possible to perform the basic operations of hunting for a character or a string of characters and to remove a substring or replace it with another substring. For example,

\[ LOC = MASK (LSTB, LSTA, 1) \]

searched for the location of LSTB within LSTA, beginning at the Ith position.

\[ CALL ISWAP (LSTC, N, LSTA, LOC) \]

replaced with LSTC, the substring of N characters of LSTA beginning at LOC. Character strings stored on DYSTAL arrays had array names which could be placed on name arrays, thus making it possible to create list structures, which were needed in analyzing sentence structures. As with other data types character strings had heads, including the length of the array and the current number of characters on it. In DYSTAL single characters could be packed into a word or the word unpacked into single characters, using integer arithmetic.

FORTRAN 77 introduced the CHARACTER data type, which greatly aids string-processing in FORTRAN. The literal constant enclosed in quote marks can now be written directly into a program. But character strings can no longer be equivalence with other data types, and hence new ways must be found to provide character strings with more flexibility, including an integer name. One method of doing this is to provide a separate dynamic storage area for character strings in a CHARACTER data type named CHAR. A function, such as LOC (‘CAT’, CHAR) can be used to store ‘CAT’ in the next available position of CHAR and return as its value the beginning and end positions within CHAR, I and J. The two numbers can be packed and stored into a single integer word:

\[ LCAT = I \times 1000 + J \]

This integer value, such as 1003, can be stored on arrays whose mode specifies names representing character strings. Names of such arrays in turn can be placed on name arrays to form list structures representing, for example, sentence structures. Knowing the name of the character string, such as 1003, it is possible to retrieve the characters through the substring reference provided in FORTRAN 77: CHAR (1:3) or its equivalent value CHAR (LCAT/1000 : MOD (LCAT,1000)). The MOD function returns the remainder term needed as the designation of the end of the substring. In sorting the strings of characters into alphabetic order, it is possible to compare
character strings, but move the positions of the names of the strings rather than the strings themselves. Here again dynamic storage allocation produces a reference to the position within the area which can be treated as an integer name.

PERMANENT FILE

A more recent addition to DYSTAL has been a save file and get file instructions to save the entire dynamic storage area on the disk file at the end of a run and to recall the same storage area at the beginning of another run. All of the important words in a program, including names of arrays, can be saved from one run of a program to another by equivalencing them to a public location in the first parameter array. In my cluster analysis-factor analysis program I can first run the clusters, examine them, and if satisfied run the program a second time beginning from the point where the clustering procedure ended. It is also possible to write a program to selectively print out any of the arrays in dynamic storage. This facility provides a means of periodically updating a complex data structure constructed as a tree structure or a chain of arrays. An error made during the course of a run may result in the file not being properly stored. By saving the previous copy of a file, it is possible to go back to an earlier version.

FORM OF THE DYSTAL LANGUAGE

A language written as FORTRAN subprograms might be imagined as a series of explicit calls to subroutines. Early in the development of DYSTAL, I realized the advantage of using functions rather than subroutines. Practically every DYSTAL routine uses the name of at least one array and it was possible to allow the name of one of the arrays to be the returned value for most of them, except those retrieving values from an array. This permitted the nesting of functions within a line of the program. This gave DYSTAL a function form of specifying a series of procedures. For example, to create an array, read 10 words into it and print it out one could write:

LSTA = IDUMP (LRD (NRD, 1, 10, (MAPL (3, 10)) )

The matrix operation

T' (T T')⁻¹ = T⁻¹

can be written in DYSTAL as

MATN = IDUMP (MPTRA (MTRAN (ICOPY (MATT)),
               MINV (MPTRA (MATT, MATT, 0», 0»)

MPTRA performs matrix multiplication of the first array by the transpose of the second and stores the resulting matrix in a newly created array and returns the name of this array. Although the function form is somewhat confusing because of the many parentheses, it does allow the stringing together of several routines on a single line. One can easily see that this ability is dependent upon the use of an integer name for an array. The nesting of functions makes the one-line arithmetic function quite useful. When the returned value of a function is not needed FORTRAN allows the use of the explicit CALL. For example, one can write CALL IDUMP (LSTA) even though IDUMP is a function with a returned value.

CONCLUDING REMARKS

DYSTAL used linear arrays in place of linked words and was therefore better able to take advantage of FORTRAN's desirable features—flexible input-output operations, use of subscripts, use of two-dimensional arrays, and arithmetic capabilities. The development of DYSTAL as a general purpose language encompassing nonnumerical procedures was dependent upon dynamic storage allocation, an integer name for arrays, the provision of an ample head for each created array. To develop these features there was heavy reliance on flexibilities in FORTRAN IV, especially the equivalencing of different data types. The X3J3 FORTRAN standards committee is proposing a core FORTRAN to be combined with modules in different application areas. According to its minutes, it hopes to eliminate EQUIVALENCE and COMMON from core FORTRAN. I think that this would be a serious mistake if the core is meant to serve as a basis for a series of more specialized languages. The core should remain as flexible as possible, and EQUIVALENCE and COMMON promote flexibility in an important way. Those not desiring the flexibility can always avoid the use of these features.

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