CARTAM

The Cartesian Access Method for Data Structures with n-dimensional Keys

Thesis by

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Opinions expressed in this paper are my own and are not to be considered an official expression by the Department of the Air Force. If any omissions or errors remain due to any lack of thoroughness or general laziness on my part, they are my own and I claim full responsibility for them.

ABSTRACT

The Cartesian Access Method (CARTAM) is a data structure and its attendant access program designed to provide rapid retrievals from a data file based upon multi-dimensional keys; for example, using earth surface points defined by latitude and longitude, retrieve all points within x nautical miles. This thesis describes that data structure and program in detail and provides the actual routines as implemented on the International Business Machine (IBM) System/370 series of computers. The search technique is analogous to the binary search for a linear sorted file and seems to run in O(log(N)) time. An indication of the performance is the extraction, in less than 25 milliseconds CPU time on an IBM 370, Model 3033, of all points within a 10,000-foot circle from a geographic data base containing approximately 100,000 basic records.

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CHAPTER I

INTRODUCTION

The age of information is upon us. Whether the computer has been developed to allow us to manipulate that information or to generate it is a moot question at this time; we do have large masses of data and must use the computer to manage them efficiently. The corporate data base has become an all-important entity in many, many cases, and the management and retrieval of information has become a far from trivial operation; witness the proliferation of data base management systems on the market today. I am not trying to address that massive subject; rather a small corner concerned with the efficient searching and retrieval of pertinent information to answer some rather specific questions.

It is extremely rare that a question is asked which requires access to an entire data base to develop the answer. In the vast majority of cases, we only need to examine certain rather small subsets of the available data. Many of these instances involve the determination of a key value or a range of key values which are then used to access the appropriate record(s) to answer the original query. So far these keys have been single-dimensional values used to probe a linear sequential file of some particular organization. There have been many methods developed to solve these types problems; Knuth devotes an entire volume to them [8]. However, if the information is keyed by multi-dimensional values, such as points in Cartesian space or locations on the surface of the earth, existing methods do not readily lend themselves to answer questions of proximity or nearness.

This paper presents a solution to the problem of efficient probes into multi-dimensional data using a method of quadrature to develop a data structure which has become very useful for questions such as: "Which resorts are within a day's drive of my home?"; "How many doctors and dentists are located in the state of Arizona?"; "What types of navigation aids are available for an airline route from San Francisco to Moscow?", etc. I shall develop this structure and the implementation of some computer programs which provide the answers to these and other similar questions.

The first of three main divisions of this thesis is a step-by-step development of the data structure and its algorithm. In order to establish an initial environment, Chapter II briefly describes some geographic data files in use at Headquarters, Strategic Air Command (SAC) and the methods that were used to query those files. After examination of the problem, the basic algorithm for our solution is developed in Chapter III. This development is in one dimension, specifically the real line, as illustration to allow comparison with existing file search strategies, in particular the binary search scheme. As such, the algorithm and structure will appear very cumbersome; the utility of the method becomes apparent in Chapter IV as the structure and algorithm are generalized to n dimensions.

The second section of this paper covers the technical aspects of the actual implementation. Chapter V is intended as a user's guide for the programmer/analyst who plans to use this n-dimensional programming techique to solve a specific problem. The implementation is as a subroutine, and this chapter describes the calling sequences and the results that are to be expected. Chapter VI goes into the internal workings of CARTAM and is maintenance information intended for the assembly level programmer who wishes to both install the system on his own hardware and/or maintain it while in use.

Once the reader is aware of the available operations, a series of examples is presented in the third section to demonstrate the use of the system. Chapter VII describes a few of the current application programs in day to day use at Headquarters SAC. These programs may prove to be useful to the reader in their own right, but the main purpose is to illustrate some methods and show how the data structure may be used. I hope that they will serve as jumping-off places for solutions to existing problems that had been deemed either unsolvable or too costly to solve using previously known methods. Chapter VIII concludes with some thoughts and recommendations on possible future applications and improvements.

The appendices, with one exception, are listings of the programs that have been in use at SAC for the last year. Appendix B contains a detailed description of a distance-calculation function or metric used to compute geodetic distances on the surface of the earth. This metric is used throughout the examples in Chapter VII.

CHAPTER II

BACKGROUND AND PROBLEM ENVIRONMENT

The data structure and access techniques as described in this thesis were developed primarily at Headquarters, Strategic Air Command, Omaha, Nebraska, and specifically applied to geographic data files used by the Joint Strategic Target Planning Staff. These particular files are used as concrete examples and are not intended to imply that these are the only possible applications; the method may be applied to any multi-dimensional data file.

The first file that was examined consists of approximately 50,000 records describing points on the surface of the earth. Most of the information in each of these records is of no consequence to this discussion except for a unique 21 character key which can be used for retrieval of a desired complete record, and the latitude and longitude which specify the location of the item on the earth.

Queries against this file by location have been limited to small areas which allowed use of a limiting procedure based upon a range of latitude values. This procedure started with an external sort based on the concatenation of latitude and longitude into a single key used for sort sequence. The resultant file was then read a record at a time, checking for inclusion inside a gross "box" defined by constant latitude and longitude, storing candidate prime keys in an internal table. Since the file is sorted with a major key of latitude, the read procedure is terminated when the input latitude is greater than the upper limit of the box. Note, however, that many records are read which will fail the gross longitude check.

After the table of candidate keys is built in main memory, a finer discrimination is made with an appropriate metric to arrive at the final set of accepted records. Some applications are summarizations that permit the packaging of several distinct queries into a single program. Since each candidate may then be examined for each criterion, a large number of the disk input operations are eliminated. However, this method is absolutely memory-bound and cannot afford a criterion resulting in a large candidate subset of the original file.

An attempt at clustering has been applied to this geographic data resulting in an "island" system. These islands have been defined such that each island is disjoint from all others with a minimum separation between any two adjacent islands. The island assignment procedure is simply a scan through the entire file as described above, looking for the island that is less than the minimum distance away from the new point. Another way to consider the clustering is that an island is the collection of all those points that are within the maximum separation of another point. This does manage to cluster points in manageable groups in most cases, but occasionally islands grow to an unwieldy size. Those islands are then manually broken up by using a smaller separation distance.

Once the islands have been assigned, a non-trivial process, subsequent processing is usually done on an island basis. An application program is given an island to process, at which time all members of that island are read into main memory and the necessary fine discrimination is applied to that subset. This methodology is not too unmanageable as long as the number of members does not get too large; anything over approximately 500 records begins to degrade performance. The island approach also limits the fine discrimination to a distance criterion no greater than the minimum separation between islands. If the desired distance is greater than the minimum separation, the method breaks down completely since the search area may need more than one island.

A second major file concerns points used to describe country and coastal boundaries for mapping applications. This data set contains approximately 100,000 data points and is stored in a sequence suitable for display on an x-y plotting device. The mapping software is capable of discarding those points outside of the area being mapped, but the entire file must be read each time, which drives the computing times to rather large values. When maps are being prepared in a batch environment for hard-copy output to be produced on a flat-bed plotter, the high CPU time may be acceptable, but not in an interactive environment with maps to be displayed on a CRT device. The only known method of operation was to pre-build desired maps overnight, which restricted a user to those, and only those, maps. If, for any reason, the user changed his mind, new maps were not available until at least the next day.

As can be seen, in many instances we have been strictly memory-bound for area type queries after reading the entire source file. The attempt at clustering the data has improved this to some extent, but only if the distance criterion is not too great. Even so, programs have been required to define internal table space to allow for the maximum size of a cluster and discrimination within the cluster required a distance calculation from the point of interest to every member of that cluster. The data structure and techniques described in the remaining chapters have removed these restrictions entirely.

CHAPTER III

AN UNUSUAL DATA STRUCTURE FOR THE REAL LINE

The problem of retrieval of information from a large file is usually solved by determining a unique key for each record, imposing an ordering operator (>) on the key field and subsequently storing the data in a linear fashion on secondary storage. Retrievals may then be accomplished by several efficient search strategies, e.g., binary search, hashing, etc. If the individual records are substantial in size, indexes are useful in reducing secondary storage access time, but the problem of searching the index has not changed.

An order is imposed upon the key values to increase the amount of available information. A linear sweep of such a file may be terminated when the key value becomes greater then the desired argument, where a random ordering would require examination of every key value in the file. This linear probing of a sorted file results in an average access of N/2 records, where N is the total number of keys in the file of interest. A much faster technique is the so-called binary search, which probes the median record in a sorted file and determines which half might contain the desired key, thus discarding the other half. Considering the remaining sub-file as a file itself, the median record of the sub-file is then probed. This algorithm terminates successfully when the desired key is found, or terminates unsuccessfully when adjacent keys in the file bracket the desired value. The binary search algorithm accesses an average of approximately log2(N) records and is said to run in log(N) time. These algorithms have an underlying assumption that the key values may be mapped one-to-one with a subset of the integers in a meaningful way which allows for the application of an ordering operator and subsequent sorting of the file.

However, if the file consists of geographic data, for example, with latitude and longitude for coordinates, the concept of ordering becomes nebulous at best. It is true that on a general purpose computer, the latitude and longitude may be defined in such a fashion as to each reside in a computer word of, say, 32 bits. These two computer words could be concatenated into a 64-bit key value, and the file could then be sorted accordingly. A problem arises when trying to decide which coordinate is to be considered as the major portion of the key. If latitude is chosen as the major key, then data points with identical latitude will be "close" together in the file, but data points with identical longitude may be "far" apart in the file structure.

Since points on the surface of the earth as denoted by latitude and longitude have their own problems in relation to a metric, let us suspend consideration of geographic points for now and concentrate on a Cartesian space, i.e., the cross product of the real line, in n dimensions. The simplest Cartesian space is the real line itself where n = 1. Thus, the following discussion will be limited to the one-dimensional case and may appear unnecessarily complicated at times, but remember that the eventual goal is the extension to n dimensions.

Let us examine a binary search strategy as applied to a linear, sorted file. In particular, consider a "uniform binary search" as described by Knuth [8,pg 413] using Shar's modification.

Given a table of records R1, R2, ... , Rm, whose key values are in increasing order K1 < K2 < ... < Km, we can search for a specified argument K, using algorithm C:

C1[Initialize]

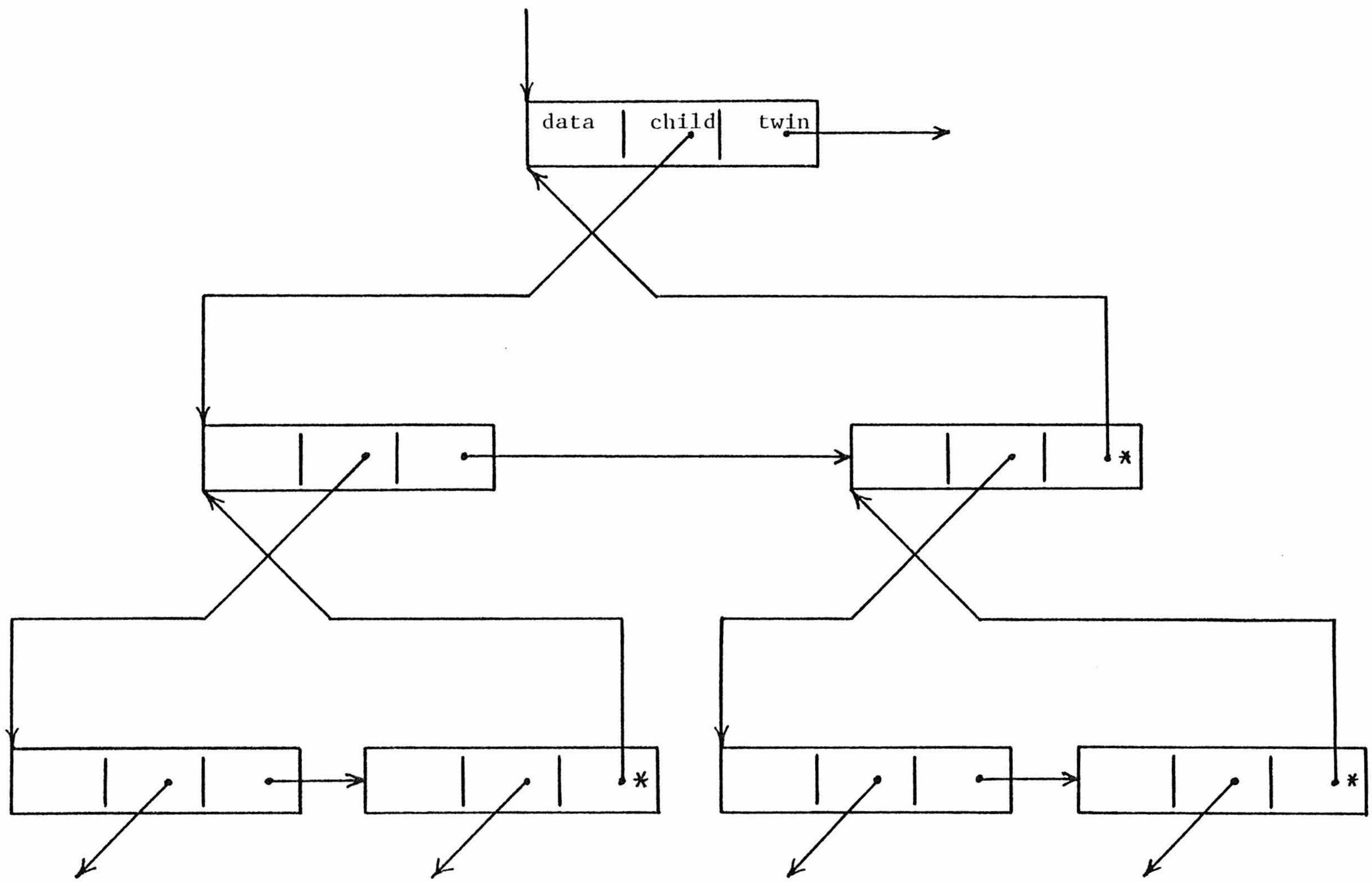
Set i := 2**k where k = $\lfloor \log2(m) \rfloor$.

(NB: $\lfloor \log2(m) \rfloor$ is the floor of log2(m) or the greatest integer ≤ log2(m); i.e., k = $\lfloor \log2(m) \rfloor$ is an integer such that k ≤ log2(m) < k + 1.)

```
        If K = Ki, algorithm terminates successfully.
        If K < Ki, set d := 2**k, go to C2.
        If K > Ki and m = 2**k, algorithm terminates
                                             unsuccessfully,
            but if m > 2**k, reset i := m + 1 - 2**j
                 where j = ⌊log2(m-2**k)⌋ + 1,
             (note that 2**k - 1 ≤ m + 1 - 2**j ≤ 2**k)
                set d := 2**j, and go to C3.

C2[Decrease i]
        If d ≤ 1, algorithm terminates unsuccessfully;
           else set d := d/2,
                set i := i - d,
                go to C4.

C3[Increase i]
        If d ≤ 1, algorithm terminates unsuccessfully;
           else set d := d/2,
                set i := i + d,
                go to C4.

C4[Compare]
        If K < Ki, go to C2.
        If K > Ki, go to C3;
        otherwise K = Ki and
            algorithm terminates successfully.
```

The choice of the underlying storage organization for our table of records is a crucial consideration. If the table is small enough to be contained entirely within the primary store of the computer, transformation of the index value i into a displacement into the table is a simple calculation. However, complete residence in primary store may be prohibitively restrictive, as a table of any appreciable size must be on secondary storage. In addition, the transformation of the index into a displacement into a multi-dimensioned table becomes complex. For these reasons, and others as will become apparent later, I have chosen to store structural information in an explicit binary tree, with modifications. Instead of the left and right links of the usual binary tree, I use the child and twin pointers of a ring structure or circular list. This ring structure as illustrated in figure 3-1* also includes the parentage information usually provided by an up-link without needing the additional pointer space in the record entry. A single bit in each record serves to indicate when a twin pointer is in fact an up-link. It is also convenient to include an

*The usual depiction of chains in linked lists in diagrams is from left to right. The usual representation of a negative number in a general purpose computer is with a bit set to "1". When a linked list chain is arranged in ascending order based on a bit string of arithmetic signs, we then have an inversion between a picture of a line segment and the corresponding list. I hope this will cause no problems to the reader.



Ring Structure Example

Figure 3-1

explicit indication as to whether a particular record is the positive or negative child of its parent record. This indicator is a single bit in the one-dimensional case.

Since the file is being stored as an explicit binary tree, note that additional records are being generated, and the concept of an "i-th" record for the algorithm becomes imprecise. Assume for the moment that the key values (Ki) are integers uniformly distributed over the interval -X to +X where X = 2**x and x is the smallest integer greater than or equal to log2(max(|Ki|)), i.e.,

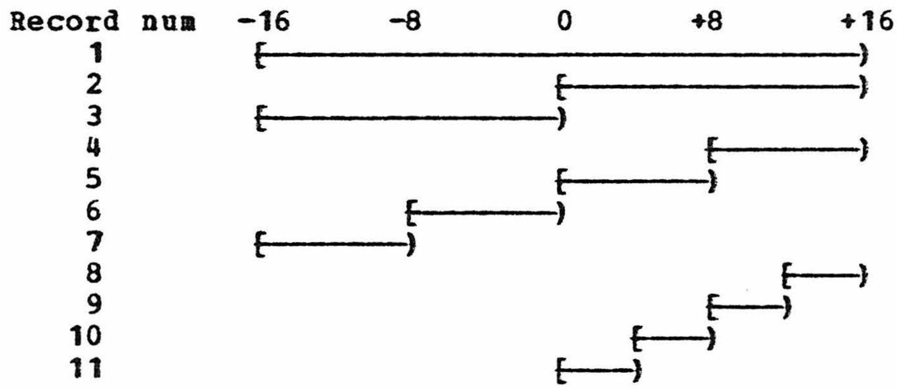
$$x - 1 < \log_2(\max(|K_i|)) \leq x.$$

Then a root record with a key value of 0 and a delta of X defines the interval = 0±X as a cover for all key values of interest, i.e., a line segment that contains all key values within it. Dividing the interval in half, the root segment now has a positive child and a negative child at the next level of detail. In the ring structure under consideration, the positive child is reached from the child pointer of the root record, while the negative child is reached by following the twin pointer of the positive child. The negative child record will have the parent indicator set showing that the twin pointer in that record points back to the parent, closing the ring. Carried to the logical conclusion, each record in the file defines a finite length line segment by specifying the center coordinate value and a delta or line length to either side of the center.

There are some important points to keep in mind about the line segments as defined by the file records. The children of a given record subdivide the line segment as defined by the parent record. In particular, if we consider a record as defining a set, which is exactly a line segment in the one-dimensional case, the set intersection of records connected by twin pointers is empty, while the union of those same records is identical to the parent record. These conditions of intersection and union also imply that the the intervals defined by the records are only half-closed, specifically, closed at the left end and open at the right end. As an example, assume that we have a set of key values such that $-15 \le Ki \le +15$. Then, $x = 4$, and the first few generated binary tree records are:

Record num	Key(Ki)	Delta	Twin ptr	Child ptr	Direc
1	0	16	---	2	---
2	8	8	3	4	+
3	-8	8	1*	6	-
4	12	4	5	8	+
5	4	4	2*	10	-
6	-4	4	7		+
7	-12	4	3*		-
8	14	2	9		+
9	10	2	4*		-
10	6	2	11		+
11	2	2	5*		-

The asterisks in the twin pointer column indicate the end of the ring, i.e., the parent pointer. Note that the delta value for each record defines the distance from the center to either end of the line segment, i.e., delta is one-half the length of the interval. Graphically this can be represented by:



If the key values are dense in the integers, i.e., the difference between consecutive keys is exactly one, then the length is halved each time we follow a child link or descend one level in the tree. Also, if we follow the twin link, unless marked as an up-link, we remain at the same level in the tree, but go to the complementary line segment. However, since key values are very rarely dense in the integers, stict adherence to the notion of equal deltas at the same level in the tree would result in extra nodes which have only one child instead of two. Therefore, we eliminate an extraneous node by replacing it in the ring with its only child. Notice that now delta values are not necessarily halved when following a child link, nor are they equal along a twin chain. Thus, it becomes useful to explicitly carry the delta value in the record entry.

The binary tree as stored on a secondary storage medium contains two basic types of records: terminal records corresponding to the original data points, and internal nodes or branch points of the tree which have been generated due to the structure definition. Each record, accessed through a pointer of value P, consists of:

1) a key or coordinate value of the center of the interval K(P)
2) a delta value of one-half of the length of the interval D(P)
3) a child pointer Child(P)
4) a twin pointer Twin(P)
5) if the record is a terminal, additional data germane to the original data record
6) various flags, such as:
   a. node or terminal indicator
   b. end of twin chain in ring, and
   c. the sign of the difference between the record's coordinate and the coordinate of the parent of this record as a direction indicator Q(P)

It is obvious that construction of this explicit binary tree generates overhead with the node records. Since extraneous nodes have been eliminated, any record with a non-null child pointer has two children. To determine just how much overhead is generated, let t be the number of terminals present, and let x be the number of generated nodes. If t' and t" are subsets of t such that t' = 2**k' and t" = 2**k" for some integers k' and k", then the number of nodes generated for the appropriate subtrees are x' and x". Applying the summation of a geometric progression with a ratio of 2, and noting that any two subtrees may be connected with one additional node, we obtain:

$$x' + x'' = (t' - 1) + (t'' - 1) + 1 = t' + t'' - 1.$$

By induction, then,

$$x = t - 1.$$

When storing the tree on a secondary storage medium, it is useful to have a master node, the root, at a location in the file that is always known. The only location that is always known is the first one; therefore, we add an additional node to the structure as the master root record, which makes the total number of generated nodes equal to the number of terminal records.

With the structure as just defined, the earlier search algorithm C is modified to give algorithm T to search for a given argument K:

T1[Initialize]

Set P := root.

T2[Compare]

Set D := K - K(P).

If D = 0 and D(P) = 0, terminate successfully.

[Record is a node if D(P) > 0.]

If D ≥ 0, go to T3;

else go to T4.

T3[D positive]

If D ≥ D(P), terminate unsuccessfully;

else set P := Child(P),

go to T2.

T4[D negative]

If D < -D(P), terminate unsuccessfully;

else set P := Twin(Child(P)),

go to T2.

When searching for a specific argument K, algorithm T may seem unnecessarily complicated. However, if the search is for all records with key values in the range K ± d, algorithm T may be extended in the following fashion with a stack, as algorithm R':

```
R'1[Initialize]

    Set P := root.

R'2[Compare]

    Set D := K - K(P).

    If D ≥ 0, go to R'3;

       else   go to R'4.

R'3[D positive]

    If D ≥ (d + D(P)), go to R'6;

       else            go to R'5.

R'4[D negative]

    If D < -(d + D(P)), go to R'6;

       else             go to R'5.

R'5[Check overlap]

    If |D| ≤ (d - D(P)),

             present entire subtree as successful,

             go to R'6;

       else set P := Child(P),

            push Twin(P) to stack,

            go to R'2.

R'6[Pop stack]

    If stack is empty, terminate;

       else pop P := top of stack,

            go to R'2.
```

Algorithm R' allows extraction of information from the binary tree structure. However, before any extractions can be performed, the tree must be built. After initialization and definition of the file by writing a master node record, repeated insertions using algorithm I' will build the file.

```
I'1[Initialize insert]
    Set K := key value of record to be inserted.
    Set P := root (pointer to master node).

I'2 Set D := K - K(P).
    Set Q := sign(D).
    If |D| < D(P), go to I'3.
    If |D| > D(P), go to I'5.
    otherwise (|D| = D(P)), so
       if Q = "+", go to I'5 (open end of interval);
          else     go to I'3 (closed end of interval).

I'3[Inside]
    Set P' := P.
    Set P := Child(P).
I'4[Walk ring]
    If Q = Q(P), go to I'2.
    If Q > Q(P), set P := Twin(P),     ["+" < "-"]
                 go to I'4;
       else  go to I'5.
```

I'5[Outside; record(I) to be inserted was inside the line segment defined by node(P') and was on the Q side of the center of that segment. The existing child on that same side, record(P), defines a line segment which does not include the new record(I). Replace record(P) in the ring with a new node(P"), and make the new record(I) and record(P) children of node(P").]

```
 Set D(P") := D(P').
 Set K(P") := K(P').
 Set Q(I) := Q.
 Repeat   [Adjust Record(P")]
     Set D(P") := D(P")/2;
     If Q(I) = "+",
        then set K(P") := K(P") + D(P"),
        else set K(P") := K(P") - D(P");
     Set Q(I) := sign(K(I) - K(P"));
     Set Q(P) := sign(K(P) - K(P"));
 until Q(I)  ≠ Q(P).
```

```
I'6[Adjust pointers]
    If Q(I) < Q(P)     ["+" < "-"]
       then
          set Child(P") := I,
          set Twin(I) := P,
          set Twin(P) := P" and mark as parent;
       else
          set Child(P") := P,
          set Twin(P) := I,
          set Twin(I) := P" and mark as parent.
```

The structure and techniques just described are much too complicated for efficient application to data keyed from the real line. However, the real line is simply the degenerate case of the eventual goal, n-dimensional space, and is described in detail for ease of illustration. As will be seen in the next chapter, the n-dimensional case is obtained from this development with quite simple extensions.

CHAPTER IV

GENERALIZATION TO n-DIMENSIONAL SPACE

The last chapter discussed at some length a rather unusual data structure for information keyed by a single coordinate. In this chapter, I will present the extensions to the data structure and algorithms which provide for the n-dimensional case and give the rationale for the design.

One of the more obvious questions concerns the use of a ring structure rather than the usual binary tree linkage of elements. After all, each record carries two link pointers while the ring has only two elements. The two pointers could just as well have been left and right links, eliminating the requirement to walk over the positive record in order to access the negative record. However, in extending to a higher dimensionality, the number of pointers required to define the structure increases exponentially.

In particular, in n-dimensional space, a given ring may contain up to 2**n entries. The ring structure allows this expansion of the number of entries with no additional pointer requirements, while a separate pointer in the record for each possible child rapidly consumes an inordinate amount of space. The ring structure also accommodates the absence of records very nicely, while individual pointers would have null values in many cases. Then there are additional physical limitations imposed by the computer hardware. As an example, consider the IBM 360/370 series of computers which use an address of 24 bits. If individual pointers were carried in a record, an application with 25 dimensions, for example, would require a record format with 2**25 pointers. This technique obviously would require a record much greater in size than the entire available computer memory.

The overhead generated by the tree structure is a direct result of the node records that define the structure. This overhead has been minimized to an extent by elimination of extraneous nodes, i.e., those nodes which would have only a single child. I have shown that in the one-dimensional case the number of node records is equal to the number of terminal records. For the n-dimensional case, this number becomes an upper bound for the worst case situation where any given node has only two children. Most nodes in the n-dimensional case will have more than two children; in other words, a twin chain will normally be longer than two entries, but in no case will the length of the twin chain be greater than 2**n.

The upper bound U for the number of nodes in a file with t terminal records is exactly equal to t. The lower bound L is attained when every node has r = 2**n children or the twin chain length is r. As was done for the one-dimensional case, t could be broken down as a summation of integer powers of r, but since r subtrees would have to be joined under a junction node to maintain optimality, and we are only interested in a lower bound, it is convenient to assume that t is already an integer power of r. Using the sum of a geometric progression once again, now with a ratio of r between successive terms, the lower bound is:

$$L = 1 + (t - 1)/(r - 1).$$

For an example, assume n = 2 and t = 65,536 = 4**8. Then the upper bound U = t = 65,536 node records, while the lower bound L = 21,846 or roughly 0.3t node records. The approximate range of 0.3t to 1.0t therefore indicates the actual number of nodes. Actual experience with a geographic data file has resulted in a file structure with approximately 0.7t node records.

These considerations, then, dictate the use of a ring structure while the record content as given in the last chapter is extended for n dimensions as:

1) n key or coordinate values for the center of a (hyper-)square Ki(P)
2) a delta value of one-half the length of a side D(P)

3) a child pointer Child(P)

4) a twin pointer Twin(P)

5) application dependent data for terminal records

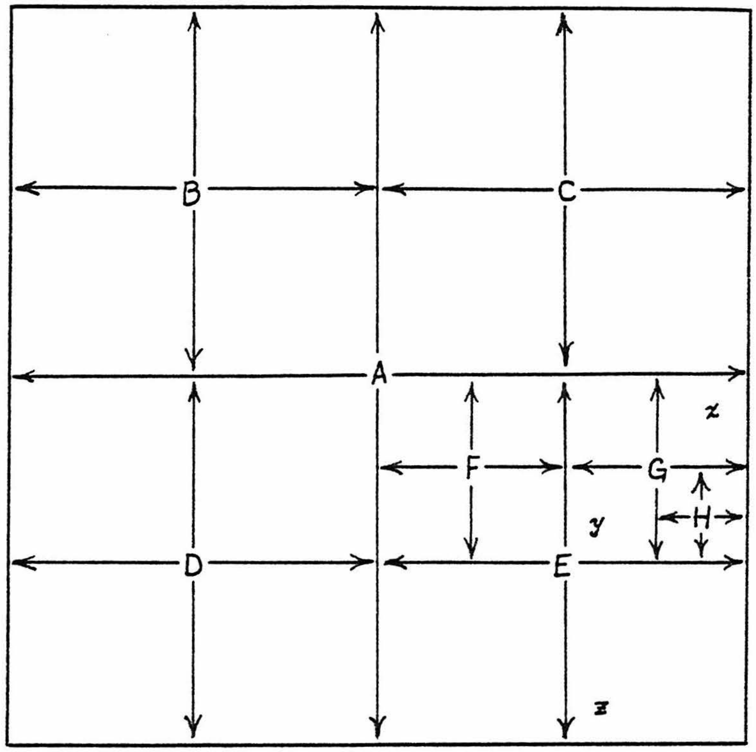
6) various flags:

   a. node or terminal indicator

   b. end of twin chain indicator

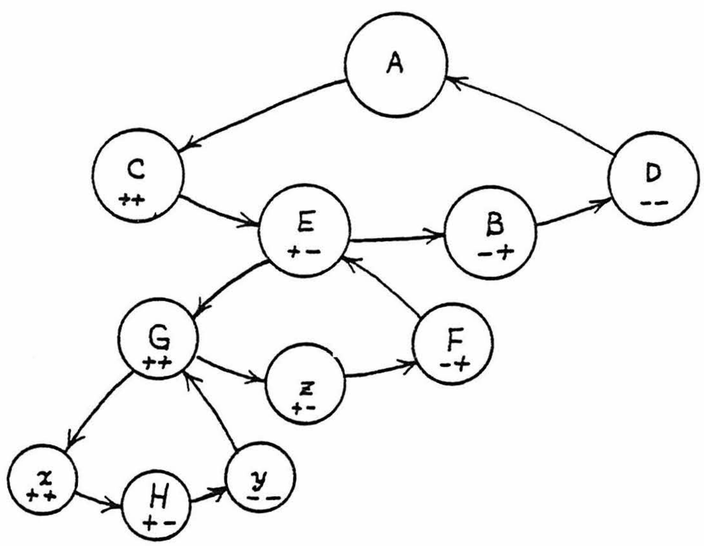
   c. a quadrant indicator of n sign bits of the difference between each coordinate of the record and the corresponding coordinate of the parent record Qi(P)

As an example of the list structure compared to an actual square from a Cartesian space, see figure 4-1. Figure 4-1a shows the example square, while figure 4-1b depicts the list as defined by the node and terminal records. The root node A defines the outer square which is then subdivided by the four children, B, C, D and E. The square defined by node E is then subdivided further by its children, F, G and z while the children of B, C and D are not shown. Node G is then subdivided even further by H, x and y. Again, the children of F and H are not shown. The terminal record z specifies the only data point in the "+-" quadrant of E, while the "--" quadrant is empty as indicated by the absence of a corresponding record in the list. Terminal records x and y likewise specify the only data points in appropriate quadrants of G. Overall, the process



Cartesian Square Subdivision

Figure 4-1a



Corresponding List Structure

Figure 4-1b

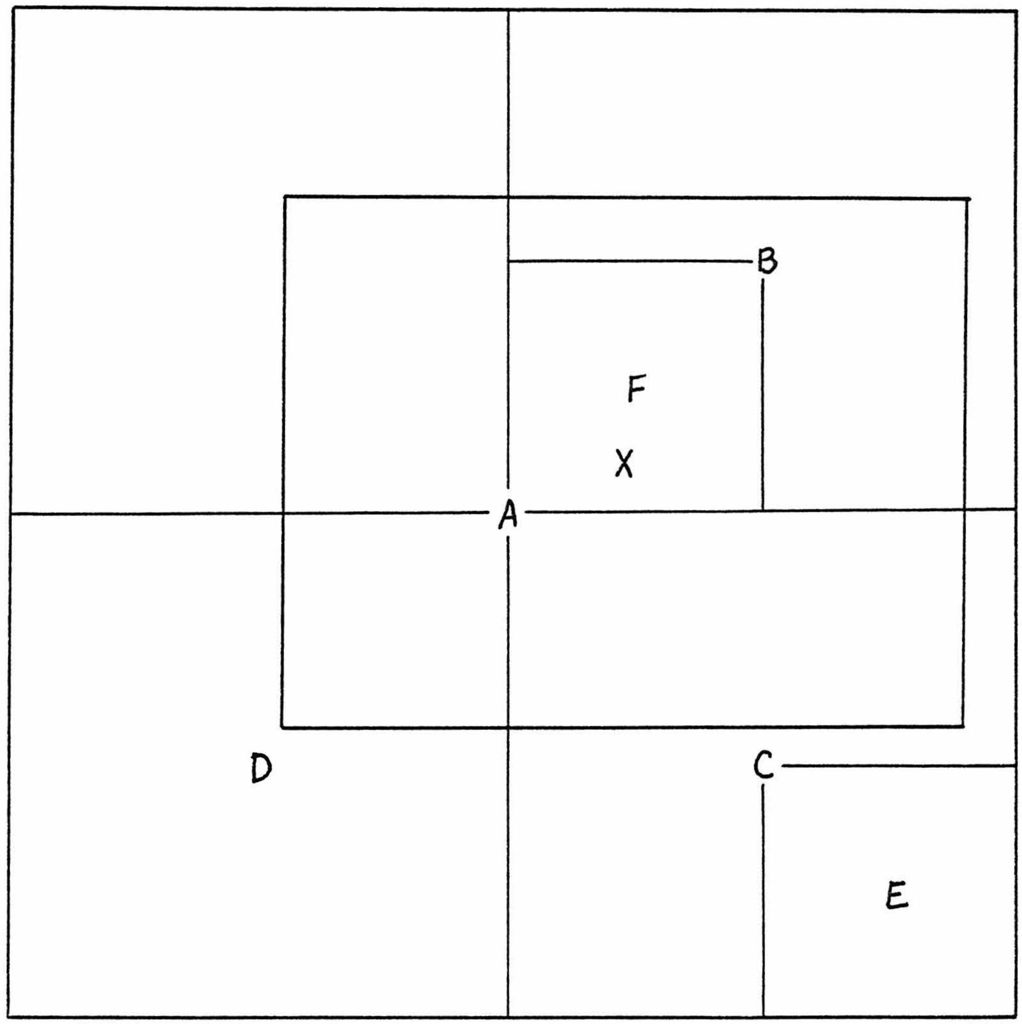
of subdivision is continued until a quadrant of a given square contains a lone terminal record; a node record is never defined unless it would have at least two children.

The n+1-tuple (K1(P),K2(P),...,Kn(P),D(P)), where each coordinate Ki(P), in connection with D(P), defines a half-open interval as in the one-dimensional case, defines a square if n = 2, a cube if n = 3, and a hyper-cube if n > 3. Since a cube may be considered a hyper-square, and examples are presented in two dimensions much more facilely than in higher dimensions, I shall use the term square in the remainder of this paper to refer to the object defined by the n+1-tuple. In a similar vein, I shall use the term rectangle when referring to the object defined by an ordered pair of n-tuples; the first n-tuple is a vector of coordinates defining the lower limits of the intervals or the lower left corner, while the second n-tuple is a vector of the upper limits of the intervals or upper right corner. Note that in the case of the rectangle, the intervals defining the sides are closed at each end.

The rectangle is used primarily in conjunction with an area search request, algorithm R', but is also useful in the insertion scheme, algorithm I', by allowing the rectangle to degenerate to a point. In both instances, the algorithms essentially ask the question, "Does a square as stored in the file intersect with the search rectangle? If it does, is the square totally inside the rectangle or vice versa?" Let's examine the area search first.

As will be seen when algorithm R' is extended to n dimensions, the question of intersection is as stated above. See figure 4-2 for some pictorial examples of possible situations with a search rectangle as defined by X. Squares A, B, C and D have non-empty intersections with X, but there is insufficient information to make a positive decision; the structure must be examined further at a finer level of detail. Square E has an empty intersection with rectangle X; therefore, we may discard the entire subtree by proceeding immediately along the twin chain. Square F is totally enclosed by X; thus, the entire subtree may be accepted as meeting the search criteria.

Returning to square D for a moment, there is additional information available, namely only one particular child of the square could possibly be of use to the search request. As will be seen, determination of the intersection involves arithmetic on the coordinates; construction of a Q type bit string is very simple. If such a bit string is constructed for each of the limit vectors, high and low, and the bit strings are then identical, the only child of interest will be exactly that child with the same bit string Qi(P).



Conditions for Intersection

Figure 4-2

The search application uses an ordered pair of n-tuples or vectors to define the rectangle, while the insertion algorithm uses a single vector as input for the record to be inserted. If we let that single vector be used twice, i.e., as a definition of a degenerate rectangle, the same set intersection function may then be used in the insertion algorithm. It will turn out to be useful to allow insertion of terminal records with identical coordinates, although differing ancillary data, which can be done by inserting a node record with a zero-valued delta and then chaining terminal records as children of that node. If the set intersection function is able to indicate whether the degenerate rectangle is totally inside the square and vice versa, and if both conditions are true, then the identity intersection would be indicated. Note that as a result of the half-open character of the square definition intervals and the closed nature of the rectangle defining intervals, the identity intersection technically could never occur. However, since computer arithmetic is finite in nature, the identity intersection can occur, but only when the intersection is between a degenerate rectangle and a node with a zero delta or a terminal, i.e., a data point, which is exactly the condition that the insertion algorithm will need.

Since the set intersection function is very important to both the search and insertion algorithms, and will be an extremely high-use section of computer code, it is developed here in detail.

Let the search rectangle X be defined by the ordered pair of n-tuples ((x1,x2,...,xn),(y1,y2,...,yn)) where xi ≤ yi. The square A from the file is defined by the n+1-tuple (a1,a2,...,an,d), where the delta value d ≥ 0. [In the following, the symbol & is for logical "and"; the symbol | is used for logical "or".]

1. At least part of the rectangle is outside of the square if the intersection of X and ¬A is not empty. The intersection is not empty if there exists an i:

$(ai - d > xi) \mid (yi > ai + d) \mid (ai + d = yi \;\&\; d \neq 0)$.

Rearranging terms,

$(ai - xi > d) \mid (yi - ai > d) \mid (yi - ai = d \neq 0)$.

Since d ≥ 0 by definition, the two terms containing yi may be combined, giving

$(ai - xi > d) \mid (yi - ai \geq d > 0)$.

2. For the converse of condition 1, at least a portion of the square is outside of the rectangle if the intersection of A and ¬X is not empty, which is the case if there exists an i:

$(xi > ai - d) \mid (ai + d > yi)$.

Rearranging terms,

$(ai - xi < d) \mid (yi - ai < d)$.

3. The intersection of the rectangle X with the square A is empty if there exists an i:

$(ai - d > yi) \mid (ai + d < xi) \mid (ai + d = xi \,\&\, d \neq 0)$.

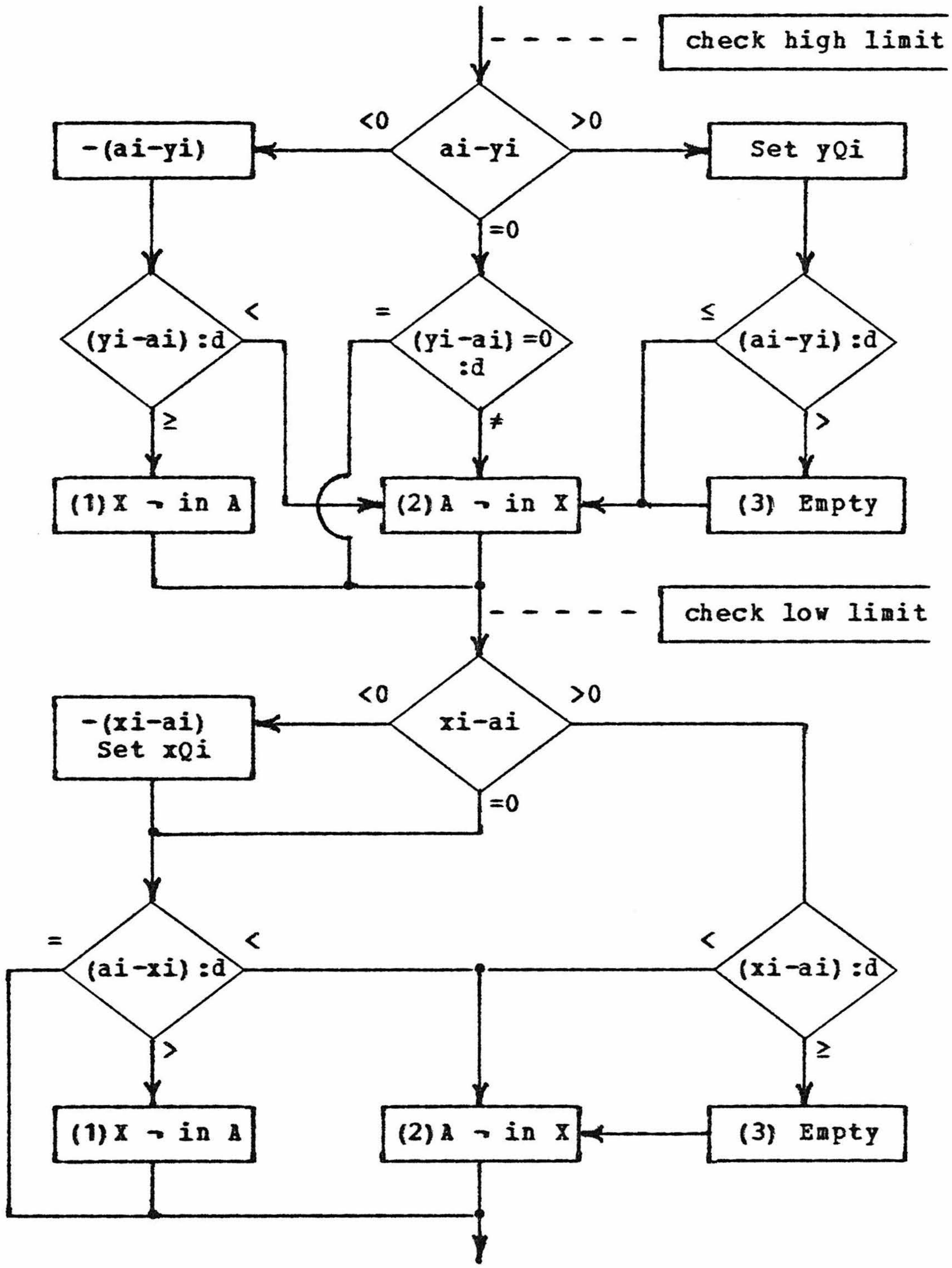
Rearranging terms,

$(ai - yi > d) \mid (xi - ai > d) \mid (xi - ai = d \neq 0)$.

As in condition 1, $d \geq 0$ allows the combination of the terms containing xi giving

$(ai - yi > d) \mid (xi - ai \geq d > 0)$.

Figure 4-3 shows a flow chart of INTERSECTION_FUNCTION after combining the three tests; the two Q bit strings are also set as appropriate.



Flow Chart of INTERSECTION_FUNCTION

Figure 4-3

Algorithm I' may now be extended to n dimensions to give us algorithm I:

```
I1[Initialize insert]
    Set Ki := coordinate values of record
              to be inserted.
    Set P := root (pointer to master node).

I2  Execute INTERSECTION_FUNCTION (record(P),Ki,Ki).
    If "Ki is inside record(P)", go to I3.
    If "Ki is outside record(P)", go to I5;
    otherwise an identity intersection, go to I5a.

I3[Inside]
    Set P' := P.
    Set P := Child(P).
I4[Walk ring]
    If Qi = Qi(P), go to I2.
    If Qi > Qi(P), set P := Twin(P),    ["+" < "-"]
                go to I4;
       else  go to I5.

I5a[Add a duplicate coordinate record]
    Set Qi := all "+".
    If record(P) is a node, go to I7;
       else set P' := P,
            go to I5.
```

I5[Outside; record(I) to be inserted was inside the square defined by node(P') and was in the Qi quadrent of that square. The existing child in that same quadrant, record(P), defines a square which does not include the new record(I). Replace record(P) in the ring with a new node(P"), and make the new record(I) and record(P) children of node(P").]

```
 Set D(P") := D(P').
 Set Ki(P") := Ki(P').
 Set Qi(I) := Qi.
 Repeat  [Adjust Record(P")]
    Set D(P") := D(P")/2;
    For i = 1 to n, do begin;
       If Qi(I) = "+",
           then set Ki(P") := Ki(P") + D(P"),
           else set Ki(P") := Ki(P") - D(P");
       Set Qi(I) := sign(Ki(I) - Ki(P"));
       Set Qi(P) := sign(Ki(P) - Ki(P"));
                        end;
 until Qi(I) ≠ Qi(P).
```

```
I6[Adjust pointers]
    If Qi(I) < Qi(P)        ["+" < "-"]
       then
          set Child(P") := I,
          set Twin(I) := P,
          set Twin(P) := P" and mark as parent;
       else
          set Child(P") := P,
          set Twin(P) := I,
          set Twin(I) := P" and mark as parent.
```

Finally, we generalize algorithm R' to the n-dimensional case of algorithm R:

```
R1[Initialize]
    Set P := root.
    (Li is the low limit vector,
     Hi is the high limit vector for rectangle X)

R2[Compare]
    Execute INTERSECTION_FUNCTION(Ki(P),Li,Hi).
    If "intersection of Ki(P) and X is empty",
                                  go to R3.
    If "Ki(P) is inside X",      Present entire subtree
                                        as successful,
                                  go to R3;
       else (overlap)
                   set P := Child(P),
                   push Twin(P) to stack,
                   go to R2.

R3[Pop stack]
    If stack is empty, terminate;
       else set P := top of stack, [pop]
            go to R2.
```

CHAPTER V

AN APPLICATION PROGRAMMER'S VIEW OF CARTAM

The structure that has been defined in the last two chapters is concerned only with a multi-dimensional key value. Depending on the specific application, the full gamut of additional information ranging from nothing, to a primary key into another file, to the entire data record could be carried in the structure. Since the proposed structure is applicable to many situations, it has proven useful to design a program that is concerned only with the structure, letting the particular application provide the necessary drivers specific to their own data and use thereof.

The data structure has been named a Cartesian Index as a result of one of the earliest applications, a latitude/longitude index of a geographic installation file. This file consisted of records varying in length from 320 bytes to 4,600 bytes that were keyed by a 21-byte key for many purposes. The Cartesian file structure was built to provide rapid answers to area search questions, but once the installations were determined, additional information was usually required. Therefore, the ancillary datum carried in the

Cartesian file in the terminal records was the 21-byte primary key value to be used for access into the master file. The Cartesian file thus became a secondary index in two-dimensional space; hence the name Cartesian Index.

The name of the program used to probe the Cartesian Index derives from IBM terminology. IBM provides many different "access methods" to process their various file structures and the program I am describing herein is intended to provide a method of access to the Cartesian Index file; the name CARTesian Access Method (CARTAM) seemed appropriate. In order to make CARTAM readily available to an end user, it is written as a subroutine, allowing the user's specific driver programs to be written in any language supporting a CALL function, usually a high order language.

Communication between the calling program and CARTAM is through a set of calling arguments or parameters. Depending on the function being requested, CARTAM expects from one to six parameters as indicated by figure 5-1. (Function codes are described in detail later.) A 28-byte communication block is required for all requests and is used to pass control and status information between the driver program(s) and CARTAM. It is the only parameter required when logically connecting or logically disconnecting a file or when deleting a record. When inserting data, CARTAM needs a

CALL CARTAM (, , , , , ,)

(generic) function	parm cnt	COMM BLOK	USER DATA	COORD VECTR	DELTA	LOW LIMS	HIGH LIMS
LOAD							
OPEN	[1]	*					
CLSE	[1]	*					
ISRT	[3]	*	*	*			
GR	[6]	*	*	*	*	*	*
Gxxx	[4]	*	*	*	*		
CHNG	[3]	*	*	*			
DLET	[1]	*					

Calling Sequence Requirements

Figure 5-1

vector of coordinate values and the ancillary data defined by the user to be stored in the terminal record. For all retrieval requests, CARTAM returns a user-data field, a vector of coordinate values and a single delta value. The GR request is treated in a special manner in that it is used to initiate a rectangle or area search which requires the two additional limit vectors defining the search rectangle. A change request applies to the user data only, but CARTAM was designed to also ensure that the coordinates of the terminal record were not inadvertently changed by the driver program which is why the coordinate vector is a required argument. On the other hand, deletion of a record, be it terminal or node, is an extreme change of coordinates and user data; there is no requirement to pass additional data to CARTAM beyond the communication block. In all cases, CARTAM looks for the required number of parameters and ignores any additional arguments that may be supplied. CARTAM will also allow, as an optional zero-th parameter, a parameter count argument indicating the number of parameters to be used. If present, this parameter count will be used, and the actual number of arguments will not be checked further. Note also that if the parameter count is present, the total number of parameters is from two to seven, as opposed to one to six.

Before any search queries can be answered, the Cartesian file must be defined and initially loaded. It is assumed that the data set has been allocated disk space; see appendix F. Definition of the file consists of telling CARTAM how many coordinates are to be stored in a record, i.e., the dimensionality of the file, and the type of arithmetic to be used, such as integer or floating point. It was intended that a Cartesian file should be loaded as a separate process, since certain efficiencies are gained thereby; thus, the use of the LOAD command to logically connect and define the file, followed by repeated use of the insert (ISRT) command to store data records. As this information is added to the Cartesian file, a new node record is constructed if necessary to account for the structure and the new terminal record is added; the relative byte address of the new terminal is returned to the driver program for any use that is desired. The load process is terminated and the file is disconnected with the CLSE command.

Once the file has been defined and loaded, subsequent processing is initiated with OPEN to logically connect it and any desired processing may then be performed. This would normally be retrievals, but the maintenance functions of insert, delete and change are also permitted. The CLSE command logically disconnects the file as before.

This gives a very rough idea as to the various ways that CARTAM is called. Since the communication block is considerably more complicated than the remaining arguments, let me defer its description for a moment and describe the formats of the other parameters first.

The parameter count is always an optional argument in those languages that use the standard IBM method of indicating the end of a variable length parameter list, namely the high order bit of the last address set to one. The IBM supported languages COBOL and FORTRAN always flag the last address, while PL/I normally does not. An assembly language programmer has the option of setting the bit or not as he chooses. If not, the parameter count argument must be supplied. The parameter count field, parameter 0, specifies the number of additional parameters in the list. As such, it must be a 32-bit fullword binary integer of the appropriate value.

The user-data area, parameter 2, is an input argument to CARTAM for insertions and changes, and an output argument for all retrievals. The user data is variable in length with two 16-bit halfword binary integer fields in the communication block controlling the actual length of the user data.

Since CARTAM allows most of the modes of arithmetic normally used on the IBM 360/370 computers, the last four parameters must take into account the length of individual coordinate values. For instance, if the arithmetic being used is halfword integer, the unit of size is two bytes, while double-precision floating-point arithmetic uses eight-byte values. Therefore, the delta value is a single unit long as determined by the mode of arithmetic while the coordinate vector and the low and high limit vectors are each n units long. The coordinate vector is an input field for insertions and changes, and an output field for all retrievals, as is the user-data area. The limit vectors are explicit input fields for a rectangle search initiation (GR) and must be distinct from the coordinate vector. They are not moved to an internal area by CARTAM; the location pointers are retained and the vectors repeatedly reaccessed during subsequent retrievals within the rectangle. Thus, the limit-vector values should not be modified during those retrievals except for unusual circumstances as they may be implicit input fields for other retrieval requests.

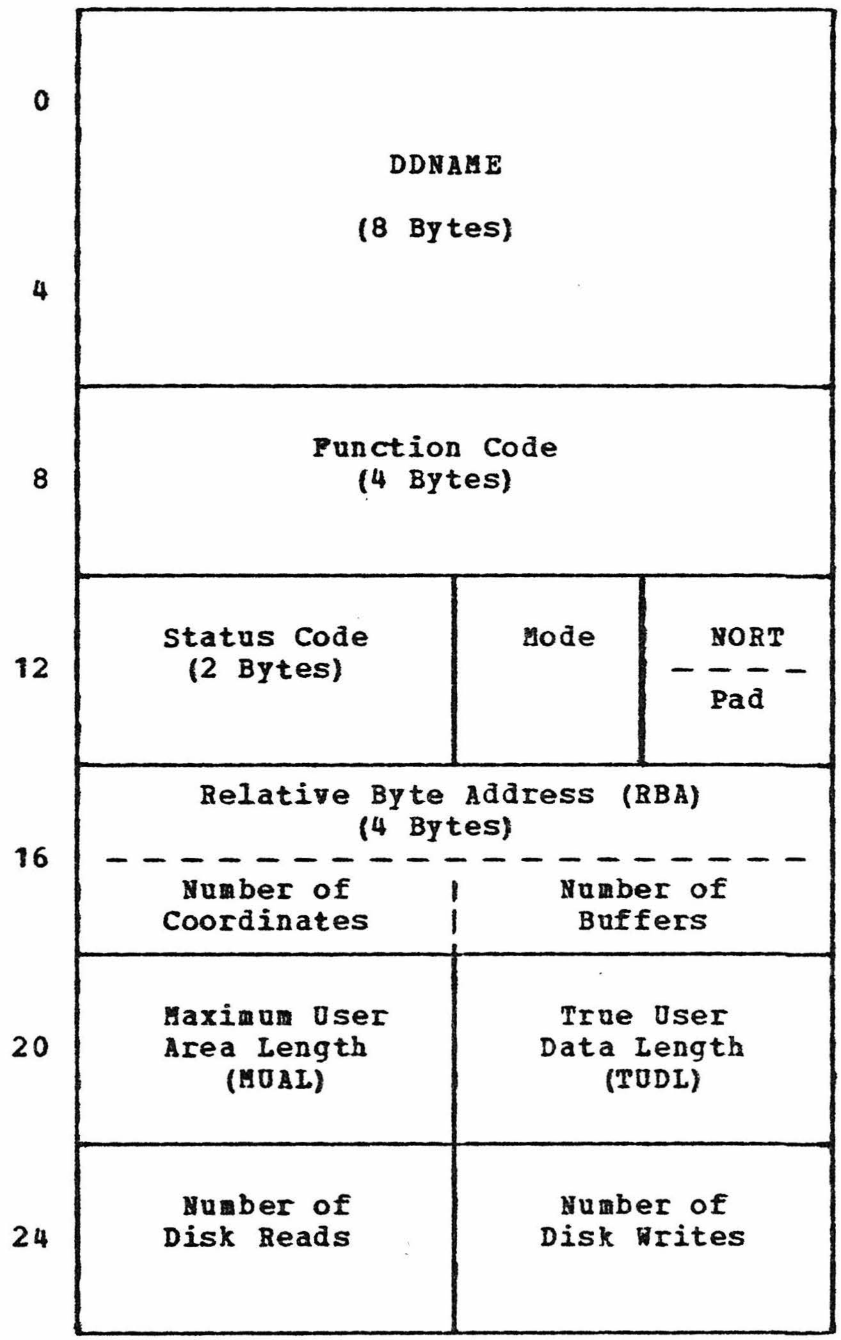
The remaining parameter, the communication block, is diagrammed in figure 5-2 and is now descibed in detail below. Following the descriptions of the fields are the lists of valid function codes and status codes as returned by CARTAM.

DDNAME

The eight-byte logical name of the file to be processed is stored in DDNAME. Since CARTAM must retain much more than 28 bytes of bookkeeping information, e.g., file control blocks, buffers, stack, etc., the DDNAME also serves as a label for that additional main memory area.

Function Code

The four-byte function code carries the request code telling CARTAM which function is to be performed. For retrieval requests it is probably better to consider this code as a concatenation of up to four subfunction codes. Valid function codes are described below.



Communication Block (28 Bytes)

Figure 5-2

Status Code

The two-byte status code provides the indication as to the success or failure of the CARTAM request. A value of EBCDIC blanks is returned if CARTAM is able to perform the function as requested. Non-blank values signal unsuccessful completion for a variety of reasons which may or may not be actual error conditions. A complete list of status codes follows the function codes.

Node or Terminal Indicator (NORT)

CARTAM returns a character to the driver program in NORT on successful retrieval requests to allow differentiation between node and terminal records. The three possible values returned by CARTAM are:

1) N - a node was retrieved
2) T - a terminal record was retrieved
3) X - a terminal record was retrieved, but the area intended to receive the user data was too short to accommodate all ancillary data as stored on the file.

Record RBA

A relative byte address (RBA) is used internally by CARTAM to build the structure pointers. Whenever CARTAM successfully inserts or retrieves a record, the record RBA is also returned to the driver program for use if desired. A Get Direct retrieval function is provided to allow direct entry into the Cartesian Index file. Examples of the use of this value would be storage of the RBA in the master record of the primary file as a cross-reference, or temporary retention of the RBA for later retrieval of selected user data not initially needed. As a cross-reference example, consider obtaining a record from the primary file by some means other than coordinate search and then desiring to find all other records within a certain distance as defined by a metric on the coordinates. Use of the RBA to position directly to the corresponding terminal record in the Cartesian Index and then climbing the structure to the appropriate level may be much faster than working down the tree from the root.

The record RBA field is also used by CARTAM to return additional error information whenever a disk operation was unsuccessful. Refer to [3,4] for an explanation of those codes. Finally, when the file is closed, CARTAM returns the high used RBA as an indication as to the amount of space on the file that was actually used.

Maximum User Area Length (MUAL)

The halfword integer in the MUAL field specifies the length of the area that is being provided by the user for a retrieval request. This number is the maximum number of bytes that CARTAM will return, see NORT above, and is also the length to which the user-data area will always be padded with the pad character, see Pad below.

True User Data Length (TUDL)

The actual length in bytes of the character string in the user-data area is placed in the TUDL field. This value must be filled by the driver program on an insert request. For retrieval requests, CARTAM stores the actual number of of data bytes, not counting pad characters, that have been placed in the user-data area of the driver program. This value will never be set by CARTAM to a value greater than that currently stored in the MUAL field.

Number Reads, Writes

Two halfword binary integer fields are incremented by CARTAM each time a physical disk read or write is performed. These fields are zeroed out during open processing. The fields are maintained and presented for information only.

The remaining field definitions have meaning only when CARTAM is requested to open the file: function code is LOAD for initial file load or OPEN. Other than the mode, these fields are alternate usages of the NORT and RBA fields.

Mode Indicator

CARTAM allows the user to specify the type of arithmetic to be used for the coordinates by supplying a value in the mode indicator if the function is LOAD; otherwise, CARTAM returns an appropriate value based on the particular file. No further reference is made to this field in subsequent calls. The four valid EBCDIC character values are:

1) H - for 16-bit halfword integer binary,
2) F - for 32-bit fullword integer binary,
3) E - for 32-bit single-precision floating point,
4) D - for 64-bit double-precision floating point.

Pad Character

In many cases, the user-supplied data being carried in the terminal records are variable-length character strings. On a retrieval request, the driver program specifies the length of the area that is being provided to receive this user data. When that area is too short, CARTAM so indicates with an "X" returned in NORT. However, when the area is longer than necessary, it will be padded out to the end with the character supplied in the pad field of the communication block.

Number of Coordinates

The dimensionality of the space being represented is determined by the number stored in this halfword field, and is the number of coordinates carried in a record of the file. The field is filled by the driver program if the function is LOAD and filled by CARTAM if the function is OPEN.

A somewhat arbitrary limit of 512 dimensions has been imposed, mainly because a limit must be established somewhere. Storage must be allocated for the bit strings generated by INTERSECTION_FUNCTION, and 64 bytes was chosen. A further limit is that the total length of a coordinate vector must be less than one-half the length of a physical record to allow storage of at least two logical records per physical record.

Number of Buffers

CARTAM obtains main memory from the operating system to use as buffers or page slots for disk input and output operations. The driver program may specify the maximum number of page slots that are to be acquired (≤ 32). CARTAM always tries to acquire at least four page slots.

Valid Function Codes

LOAD

LOAD indicates to CARTAM that the file is being defined and opened for the first time and that a series of insertions is forthcoming. The driver program must specify the mode of arithmetic and the number of coordinates to be stored. The data set referenced by the logical file name DDNAME may be an empty data set or one that had previously been used. However, any information present in the file will be destroyed.

If a file is opened for LOAD, the only valid commands are ISRT and CLSE. All others will be flagged as invalid and ignored.

OPEN

After a file has been defined, loaded, and closed again, subsequent processing is initiated with OPEN which logically connects the file to the program. All function codes are treated as valid, including ISRT which will extend the file. If the data set is empty, the open processing will fail.

On return from a successful open, CARTAM will have filled the mode and number of coordinates fields of the the communication block. A file must be opened before any other function codes will be recognized.

CLSE

CLSE requests a wrap-up, including final write of any modified records to disk. Upon successful return, the record RBA field will contain the high used RBA as an indication as to actual space utilization of the file.

ISRT

A new record is inserted as a terminal record with the ISRT request. If necessary, a new node record is also built. The RBA of the new terminal record is returned for the driver program's use as desired.

GM

This is a request to Get Master node record; it would be used to start over at the root of the tree if performing a specialized search procedure.

GP

Climbing the structure to a higher level is accomplished by a Get Parent request. CARTAM retrieves the parent record of the last record retrieved.

GT

The next record at the same level in the tree is retrieved with a Get Twin request.

GC

The first record at the next level down in the tree is accessed through a Get Child request.

GD

If the driver program has the record RBA available, the corresponding record from the Cartesian file may be retrieved directly with Get Direct.

GN

The Get Next record in hierarchical sequence function is defined as: If the previous record accessed has a child, get that child; if it has no child, get the next twin; if there is no twin, i.e., the end of the twin chain was reached, get the twin of the parent of the previous record. Repeated requests using GN will walk through the entire file structure in this sequence.

GNT

The sequence described for GN is modified by not retrieving the child of the previous record. GNT would be used when it had been determined that a subtree is to be discarded.

The last seven function codes, GM through GNT, are provided as primitives for the unusual application that needs to follow a peculiar search strategy. They will each clear parentage if it had been set earlier. The first five of these codes may also set parentage by adding a "P" as the third character of the code, i.e., GMP, GPP, GTP, GCP, and

GDP. Parentage is set to limit a search to a particular subtree of the file structure and is primarily used with the next three function codes.

GNP

Unlike previous codes where a P in position three set parentage, Get Next in Parent uses a previously set parentage to retrieve records in a hierarchical sequence within a specified subtree. The GN function will walk though to the end of the file regardless of the staring point, while repeated use of GNP will traverse only the subtree as defined when parentage was set.

If parentage has been set by the GR function described below, CARTAM also performs a check using the INTERSECTION_FUNCTION to determine if the record intersects the search area. If the intersection is empty, the subtree consisting of the record and its children is automatically discarded and the twin record is immediately retrieved. If the record is a node and the intersection is limited to a single child of that node, that particular child is immediately retrieved, and it is noted that there will be no twin of that record to be retrieved later. In both cases, the check by INTERSECTION_FUNCTION is reapplied before returning the record to the driver program. If the intersection is neither empty nor a single child, the record is returned with the appropriate information fields filled.

GNPT

Get Next in Parent, Twin, modifies the GNP sequence by skipping the child retrieval and discarding the subtree. This is done when the driver program applies a finer discrimination on a record than CARTAM can apply such as a true circle search as opposed to a rectangle search. The decision was made to only perform the simple rectangle search within CARTAM since specific applications could conceivably use any type of metric function for their discrimination purposes.

GNPL

When the driver program makes the determination that it really knows that a node record is acceptable, or, in other words, it wants all of the subtree's terminal records without bothering to apply its discriminator, a Get Next in Parent, Leaves, series of requests will flush the subtree, presenting terminal records only. The term Leaves is used since the character T was used for Twin.

GR or GA

An area search is initiated with either of the equivalent Get Rectangle or Get Area requests. The INTERSECTION_FUNCTION will be used by CARTAM to check records during this GR and subsequent GNPx requests. The stack maintained by CARTAM is flushed and the search begins at the master or root record, setting parentage for GNPx.

GR L

If the rectangle search is the exact search required by the application, placing an "L" in position four will direct CARTAM to only return the terminals that are found inside the search rectangle on subsequent GNP or GNPL requests. After a GR L request, GNP and GNPL are equivalent.

CHNG

If a Cartesian file was loaded with a substantial amount of ancillary data in the terminal records, it is useful to be able to modify that information without having to reload the entire file. The CHaNGe request tells CARTAM to replace the user data in the terminal record that had been retrieved on the previous call. CARTAM checks to see that the coordinates have not been inadvertently altered and that the new data string is not longer than the original string. If the new string is shorter, the terminal record's data area will be padded out to the original length with the pad character.

DLET

Any record in the Cartesian file may be DeLETed with the exception of the master root record. The structure pointers are adjusted to logically remove the record and a check is made to see if the ring now contains only one child. If so, the parent of the lone remaining child is replaced in its ring by that sole child. For integrity, CARTAM requires that the record be retrieved on the previous call. Note that either terminals or nodes may be deleted; deleting a node effectively deletes the entire subtree. Note also that CARTAM has no space reclamation capability -- deleting a record removes it from the structure, but the space is then unavailable for any future use until the file is reloaded!

Status codes as returned by CARTAM

ɃɃ (Two EBCDIC blanks) CARTAM successfully completed the requested function. New information has been updated as appropriate.

AD CARTAM did not recognize the function code; invalid code.

AI An error occurred while trying to open the file. A numeric error code [3, pgs 58-60] from the operating system has also been placed in the RBA field of the communication block.

AJ A logical error was detected during a disk operation. A numeric error code [3, pgs 67-69] from the operating system has also been placed in the RBA field of the communication block as for AI.

AM A mode error was detected: not H, F, E or D.

AO A physical error was detected during a disk operation. A message was written to the program log and a numeric error code [3, pg 70] has been placed in the RBA field of the communication block as for AJ.

AX Too many coordinates were specified. The maximum is 512 or a total coordinate vector length less than one-half of the length of a physical record.

CX An error was detected on a change request. The change must be on a terminal that was retrieved on the previous call, the length of the user data must be the same or less, and the coordinates must not have been altered.

DX An error was detected in a delete request. The record to be deleted must have been retrieved on the previous call. The master root record cannot be deleted.

GE The requested record was not found. GE is typically returned during GNPx processing.

GM There are no more records in the subtree being flushed by retrieving only terminals while using GNPL.

II A duplicate record, coordinates and user data, was presented for insertion; the record was not inserted.

IU The user-supplied data to be stored with the terminal record is too long. The total length of user data, corrdinates, and six bytes of structure data must be less than one-half the length of the physical record as stored on disk.

SL A short parameter list was presented to CARTAM, e.g., calling CARTAM with only the communication block and user data area, but not with the coordinate vector for an ISRT or CHNG.

CHAPTER VI

INSIDE CARTAM
FOR THE MAINTENANCE PROGRAMMER

The previous chapters have developed the basic algorithm and described the program I call CARTAM from a point of view intended for a prospective user of the system. This chapter deals with the fine detail required by a programmer assigned the task of reimplementing the system on different hardware or operating system or fixing CARTAM should it break.

The Cartesian Index file is a data structure maintained on a secondary storage medium, specifically a direct access disk or equivalent, which predicates usage of some sort of a disk address as the pointer value in the node and terminal records. The particular form of this disk address pointer depends upon the specific choice of the access methods as provided by IBM. Since we are concerned with random access to disk, there are actually only a few access methods available. The most primitive method of disk I/O provided by IBM is the execute channel program (EXCP) access method. However, this is rather too primitive as I have no desire to reinvent such things as physical error handling routines, etc. The next alternative is the Basic Direct Access Method (BDAM) which would actually work quite well except that it does not handle variable length records with any great facility. If the records are defined as relatively large, then the internal blocking and deblocking could become somewhat messy, depending on the choice of notation for the record identification. As will be seen later, though, BDAM would have been quite acceptable.

The implementation of CARTAM as described here uses IBM's Virtual Storage Access Method (VSAM) [3,4] for physical access to the disk file structure. VSAM was primarily intended as a high performance replacement for the Indexed Sequential Access Method (ISAM), but does provide support for three basic types of direct access file organizations which can be used for almost any application. Since VSAM is used for basic system support in later versions of large operating systems as supplied by IBM, e.g., OS/VS2 Multiple Virtual Storage (MVS), and it isolates a program from device dependencies better than other methods, it seemed to be a good choice.

The direct counterpart to ISAM as provided by VSAM is a key sequential data set (KSDS) which is used to store data indexed by a unique primary one-dimensional key. However, the whole intent of this paper concerns multi-dimensional keys, so we have no appropriate key to suggest use of a KSDS.

VSAM also provides a counterpart to the BDAM file organization known as a relative record data set (RRDS). Unfortunately, an RRDS requires fixed length records which are referenced by "relative record numbers", and the concerns of a BDAM data set are applicable here as well.

The third structure supported by VSAM is an entry sequenced data set (ESDS) as a counterpart to the usual sequential file organization. However, VSAM does allow random access to any position in the file by means of a four-byte relative byte address (RBA), which turned out to be ideal for my purposes. An ESDS may be viewed as a unique virtual address space defined by a four-byte address ranging from 0 to 4,294,967,295. Early in the development process, it was intended to store node and terminal records as distinct records maintained by VSAM. However, as the development proceeded and more of the performance options as provided by VSAM were incorporated, it became desirable to perform blocking and deblocking within CARTAM rather than VSAM. This became a very simple masking operation as VSAM stores information on secondary storage in units of control intervals (CI) which may be almost any size from 512 bytes to 32,768 bytes, but are physically stored as multiples of a physical record which may be 512, 1024, 2048 or 4096 bytes in length. One of the performance options used by CARTAM results in the seemingly reasonable restriction of limiting the CI size to that of a physical record or a maximum of 4,096 bytes. Each CI requires a minimum of seven bytes of control information, which leaves the remainder available for CARTAM's use. Thus, the largest record that may be stored by CARTAM is 4,089 bytes, but a further limit is rather arbitrarily imposed to limit a logical record to no more than half of a physical record in order to store at least two information records in one block. Keeping all of this in mind, CARTAM uses a VSAM ESDS as a logical memory of four billion bytes, storing the Cartesian Index file as a linked list with four-byte RBA pointer values.

An inability to extend a data set's space on disk is due to one of the performance options as used by CARTAM which prevents immediate usage of an empty or newly defined VSAM data set. Preformatting the data set with zero-filled records the first time an empty data set is opened solves the initial problem, and once preformatted, all records in the file may be retrieved on a random basis by relative byte address. However, when the original space allocation is exhausted, the data set will not automatically overflow into secondary extents when records are being inserted. If space is exhausted, there is no choice but to reallocate the file with more space and rebuild. As an indication of the actual utilization of the file space, the high used RBA is returned to the driver program when the file is closed.

Reflection at this point makes it obvious that the relative record organization of VSAM or even the Basic Direct Access Method may indeed be used. Careful selection of the physical record size to a proper power of two will allow CARTAM to operate with those file organizations with a minimum of change to the code.

The Cartesian file is built with two basic types of records, nodes and terminals. As mentioned earlier, these records consist of:

1) coordinate value(s),
2) a delta value,
3) a child pointer,
4) a twin pointer,
5) user data if a terminal, and
6) various flags.

If we examine some of these items, we find that first of all, a terminal record always has a null child pointer since terminal records are, by definition, those records with no children. The terminal record also corresponds to an original data point which has a delta value equal to zero, at least in terms of the file structure. The utility of a node or terminal flag now becomes apparent. A single bit serves to indicate the presence of a child pointer and a delta value or the mutually exclusive user data with, of course, its length.

The delta value as carried in the record also deserves some attention. While studying the algorithms, it becomes apparent that delta should probably be an integer power of two. In particular, consider a specific application on the computer using integer arithmetic. If one starts with the smallest non-zero delta value and proceeds through the tree structure towards the root, the delta is obviously such an integral power of two. Equally obviously, traversing the tree in the direction away from the root requires integer powers of two in order to prevent "gaps" due to a truncated division. If we now examine the usual internal representation of our delta value, we find that, for integer arithmetic, delta is stored as a fullword or halfword with only a single bit set to one somewhere in the (half)word. A natural method of storing this number in less space is to use a logarithmic representation, specifically log to the base of two. The normal internal representation of a floating point value is normalized hexadecimal with an exponent and mantissa. For an integer power of two, this mantissa is given by a single hexadecimal digit that is always in the leftmost position in the mantissa; only the 12 high order bits of a floating point delta are ever other than zero. Thus, we can store our delta value in the node record in only 12 bits, leaving the other 4 bits of a halfword available for some flags. Since a delta value is defined to be a non-negative number, I use the sign bit of the representation to indicate whether delta is stored as a truncated floating point number or as a logarithm. There is an apparent ambiguity for a representation of zero, since it obviously cannot be stored as a logarithm. However, a "true zero" as used by IBM for both integer and floating point arithmetic is stored as all binary zeroes, so it works out very nicely.

The Cartesian Index file records are now constructed as follows. The length of the user data stored in a terminal record is variable, but since a terminal has a defined delta of zero, we may carry the length of the user data in the space otherwise occupied by delta. The list pointers, of course, are each four bytes long, while coordinate values may be two, four or eight bytes long, depending on the mode of arithmetic being used. Finally, after packing everything together into a record, we have:

```
|_DLF|__TWIN__|_COORDS...|Q|__CHILD_|
                           |UserData...|
```

DLF is the delta/length and flags field, two bytes long. Expanding it out to the bit level:

```
0          1  11
|0_________1__45|
```

If bit 15 = "1", then "end of set" or record is the last record on the twin chain, i.e., TWIN actually points at the parent record, closing the ring.

If bit 14 = '1', then this record is a node, and bits 0-11 are the representation for delta.

if bit 0 = '1', then bits 2-7 are the log2(delta) and the antilog is obtained by shifting a value of 1 to the left this many positions,

otherwise, bits 0-11 are to be moved to a work area and extended with zeroes to arrive at a representation suitable for arithmetic.

If bit 14 = '0', then this record is a terminal and bits 0-11 represent a scaled binary integer value depicting the length of the user data string stored behind Q.

Bits 12 and 13 are unused.

The TWIN pointer is a four-byte field and is present in all records. Actual interpretation is modified by bit 15 in the DLF field.

The COORDS field contains the coordinate vector for the record and is a*n bytes long where a = 2, 4 or 8 depending on the mode of arithmetic.

Q is the quadrant indicator to label children of a parent node and is a bit string that carries the sign of the difference between coordinates of the record and the corresponding coordinates of the parent record. The length of this field is q bytes where q = (n + 7)/8 using truncated integer division. The twin chain is also maintained in sorted order using the Q field as an ascending sort-key.

The four-byte CHILD pointer appears only in node records and points to the first of two or more records at the next lower level in the structure. The coordinates and delta of the node record define a square that completely covers all of its children. The records at the next lower level define a disjoint set of squares whose union is less than or equal to the parent square.

Finally, the user-data field is a variable length field carried in terminal records only. The actual length of this area is determined by the 12 high-order bits of DLF.

The primary argument in the CARTAM calling sequence is the communication block, which is where CARTAM receives all request instructions and returns status and other information. Figure 6-1 shows the assembly dummy control section (DSECT) definition. As the DSECT is the assembly program's view of the communication block described in the last chapter, most of the entries should be self-explanatory.

```
COMMBLOK DSECT
         USING *,R11
CBDDNAME DS     CL8       DDNAME OF FILE
CBFUNC   DS     0CL4      FUNCTION CODE
CBFUNC1  DS     C
CBFUNC2  DS     C
CBFUNC3  DS     C
CBFUNC4  DS     C
CBSTATUS DS     CL2       RETURN STATUS
CBMODE   DS     C         MODE OF ARITHMETIC
CBNORT   DS     X         NODE/TERMINAL INDICATOR
CBRBA    DS     F         RBA OF RECORD RETRIEVED/INSERTED
CBMAXUDL DS     H         MAXIMUM LENGTH OF USER AREA
CBTRUUDL DS     H         TRUE LENGTH OF USER DATA
CB#GETS  DS     H         COUNTER FOR VSAM "GETS"
CB#PUTS  DS     H         COUNTER FOR VSAM "PUTS"
         SPACE
*        REDEFINITION IN EFFECT WHEN FUNC = "LOAD"/"OPEN"
         ORG    CBNORT
CBPAD    DS     C         USER DATA AREA PAD CHARACTER
CB#XS    DS     H         # COORDINATES
CB#BUFRS DS     H         # PAGING BUFFERS TO BE USED
```

DSECT of Communication Block

Figure 6-1

In order for CARTAM to operate, it needs a fair amount of additional main memory for control blocks, buffers and bookkeeping information. CARTAM must also be prepared to operate on more than one file at a time for the driver applications. Therefore, CARTAM obtains additional main memory for each file that is opened. The character string passed in as a DDNAME is used as a label to identify that block of memory as it pertains to any particular file. These blocks are linked on a bi-directional list and the proper file control area as defined in figure 6-2 is

```
FCBAREA  DSECT
         USING *,R12
FCBLABEL DS    CL8           LABEL IS FILE DDNAME
PREVFCB  DS    A             BACKWARD AND
NEXTFCB  DS    A                          FORWARD LINKS

         IFGACB DSECT=NO GENERATED ACB
         IFGRPL DSECT=NO GENERATED RPL
         DS    0D
LNACBAR  EQU   IFGRPL-IFGACB
LNRPLAR  EQU   *-IFGRPL

CISIZE   DS    F             CONTROL INTERVAL SIZE
AVSPAC   DS    F             AVAILABLE SPACE
ENDRBA   DS    F             ENDING RBA
LRECL    DS    F             LOGICAL RECORD SIZE = CISIZE-7

MVNODCS  DS    A(NODEAREA) FOR MVCL INST
         DS    F             (FLLNOD)
RCDADD   DS    A
         DS    F             (CHLDUD@)

CURRRBA  DS    F             RBA OF RCD W/ CORE ADDR IN RCDADD
BUFR@    DS    A             LOCATION AND
#SUBPOOL DS    0X
LNGBUF   DS    F             LENGTH OF PAGING AREA
PRIORT   DS    A             TOP OF LRU RING

DELWK    DS    D             EXPANDED DELTA FROM RETRIEVED RCD
PRNTDEL  DS    D             EXPANDED DELTA FOR NODEAREA

SPLTMSKS DS    0XL6          MASKS TO SEPARATE RBA'S INTO
CIMSK    DS     F            CONTROL INTERVAL RBA
DSPMSK   DS     H              AND DISPLACEMENT

         DS    H             UNUSED

LODEARGS DS    0XL6          SEPARATED RBA TO BE LOADED
LODECI   DS     F
LODEDSP  DS     H

         DS    H             UNUSED
```

DSECT of FCBAREA

Figure 6-2 (Part 1 of 3)

```
DIREC@   DS     (MAX#BFRS)XL(L'DIRECTRY) PAGING DIRECTORY

MISCFLGS DS     XL3         MISCL FLAGS
ISRTONLY EQU    B'10000000' FILE OPENED FOR LOAD
FILEXTND EQU    B'01000000' FILE HAS BEEN EXTENDED
FRSTISRT EQU    B'00000001' FIRST INSERTION HAS NOT BEEN DONE
SENDPAD  DS     C           PAD FOR USER DATA AREA

XTRAFRM  DS     A

SETFREGS DS   XL4'80'  R3   EX MASK FOR BIT STRING
         DS     F'0'   R4   COORDINATE VECTOR INDEX
         DS A(QSTRL)   R5   BIT STRING ADDRESS
         DS     F      R6   INDEX INCREMENT
         DS     F      R7   INDEX LIMIT VALUE
SETFADDR DS     A      R8   A(SET&M.0)
GRXL@    DS     A      R9   LOW SEARCH COORDINATES
GRXH@    DS     A      R10  HIGH SEARCH COORDINATES
GRFLAG   EQU    B'10000000' IF SET, DOING "GR" SEARCH
TRMONLY  EQU    B'01000000' IF SET, WANTS TERMINALS ONLY
TMPPRNT  DS     H           POINT IN STACK OF TEMP PARENT
STKPRNT  DS     H           POINT IN STACK OF PARENT
STKTOP   DS     H           TOP OF STACK

         DS     X'0'        ZEROES TO CLEAR BIT STRINGS
SETFLGS  DS     X           SET INTERSECTION FUNCTION FLAGS
SNGLCHLD EQU    B'10000000' INTERSECTION IS ONE CHILD ONLY
EMPTYSET EQU    B'00000100' INTERSECTION IS EMPTY
ENOTINX  EQU    B'00000010' SOME OF "SQUARE" OUTSIDE
XNOTINE  EQU    B'00000001' SOME OF SEARCH OUTSIDE
QSTRL    DS     XL64        BIT STRINGS
QSTRH    DS     XL64        OF DIFFERENCE SIGNS
QSTRO    DS     XL64

         DS     D           UNUSED
         DS     D           PERMANENT PIECE OF STACK
STACK    DS     128D
MAXSTKL  EQU    *-STACK
```

DSECT of FCBAREA

Figure 6-2 (Part 2 of 3)

```
FILECNTL DS     XL32        FILE CONTROL INFORMATION
         ORG    FILECNTL
HIUSDRBA DS     F           CURRENT HIGH USED RBA (ISRT USES)
FLMODE   DS     C           H | F | E | D
         DS     C           UNUSED
FL#COOR  DS     H           # COORDINATES
FLLCV    DS     H           (FL#COOR)*(FLLCOOR)

DELTA@   EQU    0,2         12 BITS
RCDFLGS  EQU    1,1          4 BITS
PARENT   EQU    B'0001'     END OF TWIN CHAIN
NODRCD   EQU    B'0010'     RECORD IS A NODE
TWIN@    EQU    DELTA@+L'DELTA@,4 TWIN POINTER
COORDS@  EQU    TWIN@+L'TWIN@ START OF COORDINATE VECTOR
*QSTR@   EQU    COORDS@+(FLLCV)
QSTRLM1  DS     H           Q STRING LENGTH MINUS 1
CHLDUD@  DS     H           CHILD PTR|USER DATA DISPLACEMENT
FLLNOD   DS     H           TOTAL LENGTH OF A NODE RECORD
* = L'DELTA@+L'TWIN@+(FLLCV)+(QSTRLM1+1)+L'CHILDPTR <= 2000

*                           SO FAR 16 BYTES ARE LEFT
         ORG
NODEAREA DS     XL2000      NODE CONSTRUCTION WORKSPACE
FCBLNG   EQU    *-FCBLABEL HOPEFULLY < 4096
         ORG    *-132
RPLMSG   DS     CL132'RPL MESSAGE AREA'
```

DSECT of FCBAREA

Figure 6-2 (Part 3 of 3)

located each time CARTAM is entered. If a file control area cannot be located and the function code is other than OPEN, LOAD or CLSE, a status code of 'AD' is returned indicating an invalid function code. If an area is located and the function code is OPEN or LOAD, a status code of 'AD' is again returned.

FCBAREA defines an area of main memory that is acquired on a page boundary, i.e., an even multiple of 4096. This is the main work area for CARTAM for the particular file being processed.

FCBLABEL is the file name from the communication block and is used as the identifying label for the work area.

PREVFCB and NEXTFCB are forward and backward links for the work area(s) and are anchored inside CARTAM directly. Since the register save area is also inside CARTAM, CARTAM is not re-entrant, but is serially re-usable.

IFGACB and IFGRPL are IBM supplied definitions of the access control block and request parameter list for the VSAM access method. CISIZE through LRECL receive information about the file for later use. ENDRBA indicates whether the data set already has information or if it must be preformatted; if so, AVSPAC is used to find out how long the data set is.

The four words beginning at MVNODCS are set up to load the control registers for an MVCL or CLCL instruction, each of which requires two addresses and two lengths. The fourth register also carries a pad character as the high order byte.

CURRRBA is used to retain the RBA of the most recently accessed terminal or node record. It is primarily used for checking on a delete or change request.

BUFR@, #SUBPOOL and LNGBUF refer to the additional main memory obtained for input/output buffers or the paging area. PRIORT points at the top of the priority ring that is maintained for the paging directory (DIREC@) in a least recently used (LRU) manner.

DELWK is the work area for an expanded delta so that it may be used in arithmetic statements. It is filled in the LODE routine every time a new record is accessed. PRNTDEL is the corresponding expanded delta value for the record being constructed in NODEAREA.

SPLTMSKS is composed of CIMSK and DSPMSK which are used to split an RBA pointer into an RBA address of the control interval and a displacement. DSPMSK = CISIZE - 1 because CISIZE is an integer power of two as defined by VSAM. Then, CIMSK is simply the one's complement of DSPMSK.

The masks are used as logical "and" masks against LODECI and LODEDSP which compose LODEARGS. The paging directory is then searched for LODECI; if not there, the oldest slot is picked to read in the proper control interval. The translation is completed by adding LODEDSP to the page frame address to arrive at the main memory address of the data record being referenced.

MISCFLGS are miscellaneous flags; use is obvious.

XTRAFRM is an extension of the paging directory. IBM provides a PGRLSE macro to specify release of a virtual memory area. This macro is used in the input/output routine as an attempt to gain efficiency by releasing a virtual page just prior to a read operation so that the operating system will not bring that page in from paging store simply to write over it with a new record from disk. The parameters for PGRLSE are the low address and the high address plus one of the area to be released; these addresses are exactly the page frame addresses as stored in the paging directory for the page slot being released along with the address of the next slot. XTRAFRM provides that "next slot" frame address for the last paging directory entry.

SETFREGS through GRXH@ are preset values for the general purpose registers R3 through R10 used in the set intersection function. R3 contains a one bit mask to set a position in the Q bit string as addressed by R5. R4 is the index into the various coordinate vectors and is incremented by the value stored in R6 in a BXLE instruction. R7 contains the limit for R4, i.e., (R7) = n*(R6) - 1. R8 has the address of the entry point into the appropriate arithmetic dependent code while R9 and R10 point at the lower and upper limit vectors. The set function also assumes that R1 points at the current node or terminal record being examined. SETFLGS carries the results of the set intersection function while QSTRH and QSTRL have been set according to the arithmetic differences during the course of the calculations. QSTRO is used only during insertions to adjust the coordinates of the new node record being built as a parent.

TMPPRNT holds the location in the stack that is to be considered a temporary parent for the purpose of presenting, without further checking, all terminal records in a subtree that has been accepted.

STKPRNT holds the location in the stack that is to be considered the parent level for Get Next within Parent processing while STKTOP always points at the top of the stack.

STACK is a 128 entry stack used to remember the parent backtrack chain along with the next twin entry. The parent backtrack trail is retained primarily for insertions to climb the parent chain in hopes that consecutive insertions were relatively "close" to each other, thus reducing chain chasing as much as possible. The twin pointers are retained for GNP processing to negate the requirement for input of a parent record solely to retrieve the twin pointer when accessing the parent's twin. Each entry in the stack is two words: the left word carries the parent backtrack trail, the right word carries the next twin. Upon exit from CARTAM, the top entry of the stack has zero in the left position; the right word has the child pointer of the record being returned to the driver program, which is zero if the record is a terminal. The second entry down in the stack has the

RBA of the record being returned as the left side value which will be the parent as the stack grows. The right side of this stack entry is the twin pointer from the returned record unless the record is marked as the end of a twin chain, in which case, zero is stored. This entry is always the next twin for GNP. As the stack is popped, either because the child value at the top was zero or the subtree is being bypassed, the twin value is picked up from the right side and stored in the left side. The twin and child pointers of that new record are then stored as before. Obviously, if the twin pointer was zero, the stack is simply popped one more level.

FILECNTL is a 32 byte area of control information to be stored on the file at RBA = 0. This information is derived from data provided when the function code was LOAD and then stored in the file. When the function code is OPEN, these 32 bytes are retrieved from the file and stored here. Only 16 bytes are used at this time.

HIUSDRBA contains the number of bytes used by CARTAM for insertions. It is the actual RBA of the next available byte in the VSAM file and is obtained and updated whenever a new record is inserted. If it has changed since the file was opened, the control information is rewritten to the file.

FLMODE holds the EBCDIC character defining the mode of arithmetic: H, F, E or D.

FL#COOR is a halfword integer value specifying the number of coordinates (n) in a coordinate vector.

FLLCV contains the actual length of a coordinate vector in bytes. (FLLCV) = (FL#COOR) * 2, 4 or 8 as appropriate.

DELTA@ through COORDS@ are symbolic equates defining the internal record structure. QSTR@ would be an equate to the beginning of the Q bit string in the record, but, due to the variable length of a coordinate vector, is stored as a value equal to COORDS@ plus the length of a coordinate vector.

QSTRLM1 holds the length of the Q bit string less one. The IBM execute instruction requires this value for proper operation. (QSTRLM1) = ((FL#COOR) - 1)/8 using integer division.

CHLDUD@ has the displacement to the child pointer for a node which is also the displacement to the user data for a terminal record. (CHLDUD@) = (QSTR@) + (QSTRLM1) + 1

FLLNOD holds the total length of a node for this file. The value stored in FLLNOD is 4 more than that in CHLDUD@. In order to be able to store at least two logical records per physical record or control interval, the total length must be less than an arbitrary 2000 bytes or one-half the physical record length, whichever is smaller.

NODEAREA is work space to remember the contents of a possible parent record for insertions. That information is then modified while constructing the actual record that is to be entered into the file. RPLMSG is an overlay of the last 132 bytes and is used only by VSAM to return an error message. If such an error had occurred, any temporary record would be useless anyway.

Appendix A contains the entire assembly listing of the CARTAM routine. Within the routine are several logical units that are described here.

The LODE section of code is a closed subroutine to convert an RBA to a main memory address. The RBA is split into a control interval RBA plus a displacement into that CI. If the CI is already in memory, it is logically moved to the top of the LRU ring, the displacement is added to the proper frame address in R1, the delta is expanded, the twin pointer from the record is inserted in R2, and control is returned to the point of call. If the CI was not in main memory already, the oldest slot is determined from the end of the end of the LRU ring and the CI in that slot is written to disk if it had been modified. The new CI is then read into the frame and treated as above. The logic of this section of code was modeled after the paging scheme as described in in REL Paging Services [9].

The overall logic of CARTAM is actually quite simple. On entry, a search is made for the proper FCBAREA, building a new one if necessary, the function code is examined, and control is transferred to the appropriate section. Most retrievals eventually go through the RTNVALS section which moves the coordinate vector to the driver program's area along with the user data if the record was a terminal. The area receiving the user data is padded out with the pad character in any case. The expanded delta value is also placed in the proper location and the NORT indicator is set.

A Get Master record is a request for the master node and would be issued if the driver program wished to restart an unusual search strategy. The stack pointers are reset to put the master RBA in the master (-1) position of the stack which is then adjusted with twin and child pointers as usual.

The RBA for a Get Direct request probably will not be found in the stack, but the stack is checked just to make sure. Note that a GD request will probably flush the stack which must be considered in Get Parent and Get Next requests.

The Get Twin and Get Child requests are simple pops of the stack. If a zero value is picked up after the pop, an indication of no record found is returned: STATUS = GE. The Get Parent is slightly more complicated due to the possibility of GD requests flushing the stack. If the stack is exhausted during the pop operation, the twin chain must be followed to find the next parent record. All of the requests so far described may set parentage, in which case the location in the stack of the record being returned is stored in STKPRNT as a parent marker.

The Get Next and Get Next in Parent operate in a similar fashion except that GNPx will terminate at the parentage as stored in STKPRNT while GN will continue through the twin chains even after the stack is exhausted. GNPx processing is also slightly more complicated because the INTERSECTION_FUNCTION is used if the search had been initiated by a GR request. If the INTERSECTION_FUNCTION determines that only one child of a node is useful, that child is retrieved immediately and the next twin entry in the stack for that record is cleared, indicating no further records along that chain. If the record is a node and the fourth position of the function code is an "L", a branch is taken to the top of this section of code to immediately retrieve the next record.

The insertion algorithm attempts to take advantage of resident records and any actual proximity of consecutive inputs by popping the stack, using the parent backtrack trail. The stack is repeatedly popped until a node record is found which defines a square that actually contains the point X which is to be inserted. INTERSECTION_FUNCTION is invoked in each instance with the X coordinate vector used as both the low and high limit vectors. When a good parent has been found, CARTAM turns around and descends the tree structure. Since a node P was found that contains X, it is known in which direction X lies in relation to the center of P because INTERSECTION_FUNCTION sets QSTRH and QSTRL in the FCBAREA. Thus, CARTAM walks the child/twin chain looking for the child with a matching Q string. If no record is found with a matching Q string, X is inserted as a terminal record in the proper position in the chain.

If a record C was found with a matching Q string, INTERSECTION_FUNCTION is invoked again to determine if X is inside C. If truly inside, CARTAM treats record C as the P node and loops back to continue with the descent. If the intersection was empty, a new node must be constructed to replace C in the chain we have been following. This new node becomes the parent of C and the new terminal X and the coordinate values of the new node are adjusted to ensure that C and X have differing Q strings in relation to their new parent.

If the intersection of C and X was an identity intersection, the coordinates of X matched the coordinates of C and C is either a terminal or a node with a zero-valued delta. If C is itself a terminal, it is replaced in its chain with a new node with a delta defined as zero and both

C and X are chained as children of that new node. If C was a node with zero delta, X is simply added as another child. In this case, all children, including C and X, have identical Q strings, indicating an all positive direction.

Change and delete requests require that the record be retrieved on the immediately preceding call to CARTAM. A change allows only the user data to be modified and it must not be extended. To ensure that a change request is not incorrectly used to change coordinates, CARTAM requires the coordinate vector which must still agree with the record in the file. If the coordinates still match, and the record is is indeed a terminal, the user data is moved from the driver program's area into the file record, replacing the user defined data in entirety.

Only terminal records may be changed, but both terminal and node records may be deleted. A record is logically deleted by adjusting the pointers to skip over it. Space is not reclaimed! After the pointers have been adjusted, the length of the chain is examined to ensure that the chain is at least two members long. If the chain has only one member, the parent of the chain is replaced in its ring by the sole remaining child.

CHAPTER VII

CARTAM IN USE

The preceding discussion gave some general search algorithms with no particular rationale behind them. Let us look at some specific applications that have been implemented at Headquarters, Strategic Air Command. Our computer environment is an IBM System 370, Model 3033, using OS/VS2, Multiple Virtual Storage (MVS) as the operating system. Secondary storage consists of IBM 3330 Model 1 and Model 11 disks and IBM 3350 disks. In all of my examples, the data are points on the surface of the earth defined by latitude (lat) and longitude (lng).

The first file is stored on 18 cylinders of a 3330 disk volume and contains roughly 100,000 terminal records as data points, each carying an average of 15 bytes of user-defined information. The latitude and longitude in this file are stored as arc seconds in signed binary integers with the convention of north and east positive. The driver program to load this file executes in approximately 55 seconds of central processor (CPU) time and 15 minutes elapsed time in our normal batch production multi-programming environment.

The metric function used to calculate distance on the earth is an implementation of a great elliptic evaluation which provides geodetic distance in meters; see appendix B for a discussion of VECTOR. Since this metric function tends to be expensive in computation, an estimator value has been devised which provides an estimated radius in meters of a circle guaranteed to completely enclose the square defined by a node or terminal record's coordinates. The value of this estimator E is:

E = 45.0 > 43.645 = sqrt(2)*(1852 meters/60 arc secs)

(1852 meters per nautical mile;
1 nautical mile per arc minute;
1 arc minute per 60 arc seconds)

It might seem that a better estimate of the radius for a circumscribing circle could be obtained by using VECTOR to measure the distance from the center of the square to the lower left corner for example. Unfortunately, some of the nodes near the root of the tree carry latitude values in the range of ±45°. With VECTOR calculating geodetic distance, a much smaller number than expected is the result. Since search strategies will not be attempting any accurate determination of the inclusion of an area inside a node-defined square, rather the reverse, the upper bound approach with E was chosen.

Probably the simplest application of CARTAM is to search for those data points within an arbitrary circle. As a first approximation to the desired circle with center coordinates (lat0,lng0), define a search rectangle to enclose the final desired circle. The delta latitude value is the appropriate number of arc seconds equivalent to the circle radius (D0), while the delta longitude is that same number of arc seconds divided by the cosine of the latitude to allow for convergence at the poles. Therefore, the limit vectors are:

lvec = (latl,lngl) and hvec = (lath,lngh) where

latl = lat0 - D0, lngl = lng0 - (D0/cos(lat0)),

lath = lat0 + D0, lngh = lng0 + (D0/cos(lat0)).

See figure 7-1 for the conditions that will be tested by algorithm CS below. Within the diagram:

line AX = DELTA(A) * E

line BY = DELTA(B) * E

line CZ = search radius = D0

line CA = VECTOR distance from C to A

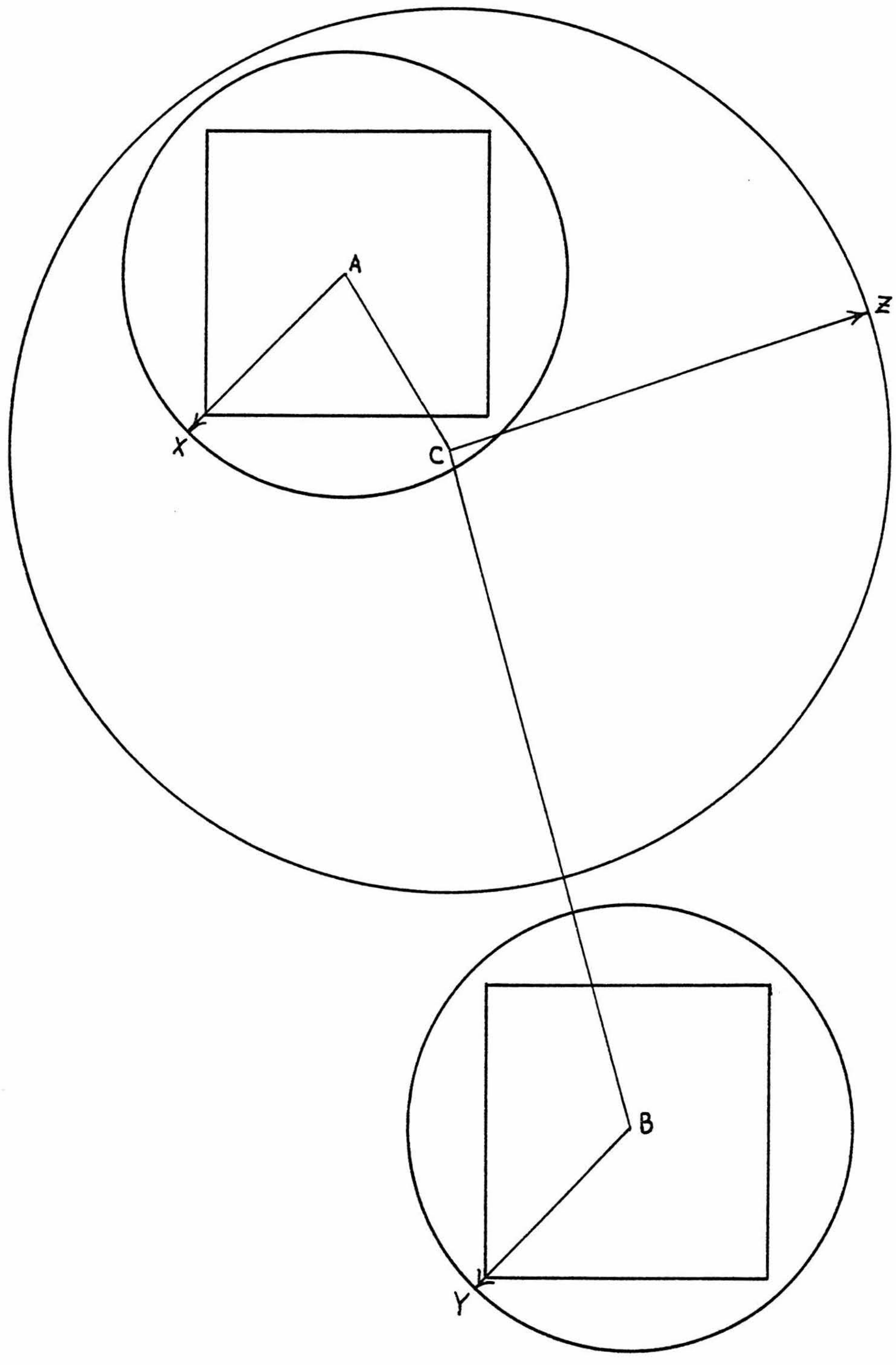
line CB = VECTOR distance from C to B

square A is inside search circle because

CA < CZ - AX

AX < CZ - CA

AX < -(CA - CZ)



Circle Search Conditions

Figure 7-1

```
        square B is outside search circle because
             CZ < CB - BY
             BY < CB - CZ
```

Moving "GR" to the function code initially, we have:

```
Repeat
   CALL CARTAM (COMM_BLOK, USER_DATA,
                COORDS, DELTA,
                lvec, hvec);
   if STATUS_CODE = SPACES, then begin;
      Set AX := E * DELTA;
      Set CA := VECTOR(lat0,lng0,lat1,lng1);
      if AX ≤ CZ - CA, then begin;
                    /* square A for example */
            Set FUNC := 'GNPL';
            repeat
               if TERMINAL, then
                   Present terminal records
                           as successful;
               CALL CARTAM (COMM_BLOK, USER_DATA,
                            COORDS, DELTA);
            until STATUS_CODE ≠ SPACES;
            Set FUNC := 'GNP ';
            if STATUS_CODE = 'GM', then
               Set STATUS_CODE := SPACES;
                            end;
```

```
        else
           if AX < CA - CZ, then
              Set FUNC := 'GNPT';
                  /* discard subtree (square B) */
           else
              Set FUNC := 'GNP ';
                  /* to examine next level down */
                                           end;
  until STATUS_CODE ≠ SPACES;
```

This algorithm asks CARTAM for successive nodes and terminals inside an initial search rectangle. As a record is returned by CARTAM, it is checked to see:

1) if it is entirely within the final circle, then all terminals of the subtree are presented as found;
2) if it is entirely outside the final circle, the subtree is discarded;
3) if neither condition is met, the tree structure is descended one more level to examine the children.

The process is continued until no more nodes or terminals remain in the search rectangle to be examined. See appendix G for a COBOL program written for this task.

This particular driver program with the highly original name of ONETEME (variant of ONETIME) has been used extensively as a test vehicle during the development of CARTAM. It was written to display the results of a primitive circle

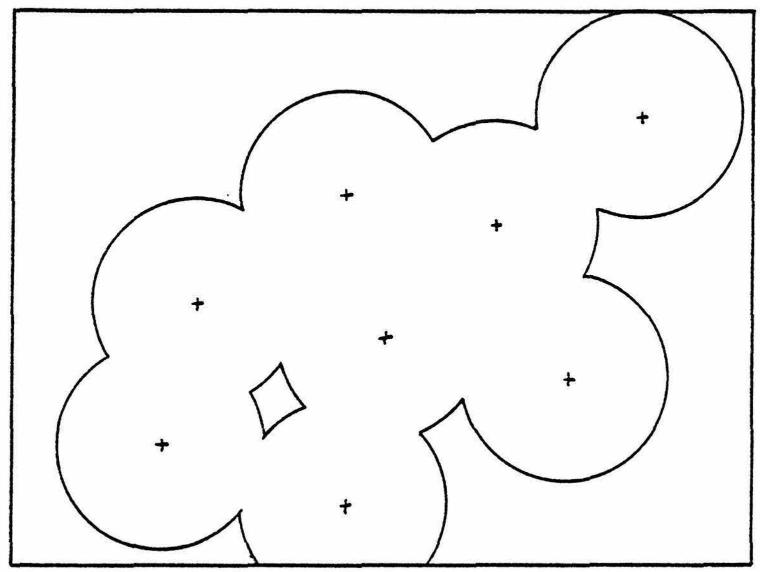
Performance Statistics

Number of search points	1	50	100	200	300	400
8 page slots						
CPU seconds for run	.19	1.38	2.60	5.01	7.47	9.89
CPU seconds/ search point	.19	.0243	.0243	.0242	.0243	.0243
Number of reads/search point						
minimum	22	16	16	16	16	16
mode	22	24	24	22	24	24
mean	22	24.04	24.09	24.01	24.02	24.30
maximum	22	32	34	34	41	51
16 page slots						
CPU seconds for run	.19	1.29	2.41	4.55	6.98	9.78
CPU seconds/ search point	.19	.0224	.0224	.0219	.0227	.0240
Number of reads/search point						
minimum	21	15	15	15	15	15
mode	21	23/24	20/23	20	22	23
mean	21	22.28	22.23	22.14	22.19	22.43
maximum	21	30	30	30	35	36
32 page slots						
CPU seconds for run	.20	0.95	1.69	3.17	4.83	6.55
CPU seconds/ search point	.20	.0155	.0151	.0149	.0155	.0159
Number of reads/search point						
minimum	21	1	1	0	0	0
mode	21	10	12	12	11/12	12
mean	21	11.74	11.15	10.69	10.77	10.68
maximum	21	21	21	21	25	25

Figure 7-2

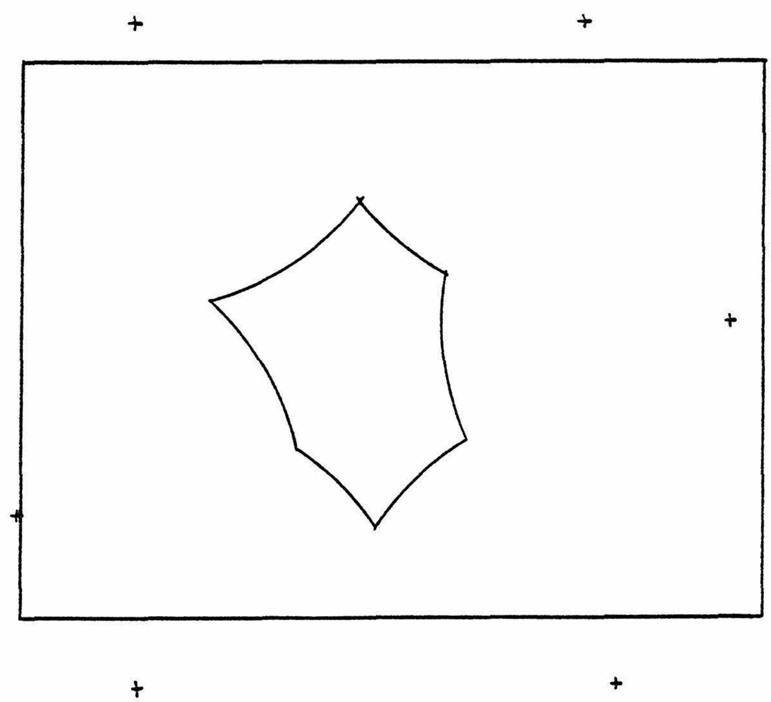
search as applied against the installation index file. Input is the Cartesian Index file which is to be searched, and a file of control cards, each of which contains the latitude and longitude of the center of a search circle. Test runs have usually been made with a 10,000 foot radius for the search. The overall logic consists in reading a control card, searching the Cartesian file for all data points within 10,000 feet and printing the accepted records. This procedure is then repeated for each card in the input file. Figure 7-2 presents a table of selected statistics as an indication of performance. The table is cumulative in nature; the different lengths of runs are from termination at specified numbers of control cards. For example, the statistics for 300 points were obtained by extending the 200 point run by 100 more points. The entries for number of reads are the numbers of physical disk accesses that were made for each control card read during the run.

An obvious extension to the circle search is a search for those installations inside the area defined by the mathematical union of k circles as shown in figure 7-3a. We modify algorithm CS by defining the search rectangle to include all circles and checking distances to the center of each circle instead of just the one; initially setting a flag to indicate "outside-all-circles", a loop is executed on the metric. Once again moving "GR" to the function code initially, we now have:



Inclusion Area Search Example

Figure 7-3a



Exclusion Area Search Example
Figure 7-3b

```
Set ACCEPT_SQUARE := "inside-a-circle";
Set REJECT_SQUARE := "outside-all-circles";
Repeat
   CALL CARTAM (COMM_BLOK, USER_DATA,
                COORDS, DELTA,
                lvec, hvec);
   if STATUS_CODE = SPACES, then begin;
      Set AX := E * DELTA;
      Set flag := "outside-all-circles";
      for i = 1 to n, do begin;
         Set CA := VECTOR(lati,lngi,lat1,lng1);
         if AX ≤ CZ - CA, then
             Set flag := "inside-a-circle"
         else
             if AX > CA - CZ, then
                 Set flag := "overlap-a-circle";
                        end;
      if flag = ACCEPT_SQUARE, then begin;
           Set FUNC := 'GNPL';
           repeat
              if TERMINAL, then
                  Present terminal records
                          as successful;
              CALL CARTAM (COMM_BLOK, USER_DATA,
                           COORDS, DELTA);
           until STATUS_CODE ≠ SPACES;
```

```
            Set FUNC := 'GNP ';
            if STATUS_CODE = 'GM', then
               Set STATUS_CODE := SPACES;
                                   end;
      else
         if flag = REJECT_SQUARE, then
            Set FUNC := 'GNPT';
                /*  discard subtree  */
         else
            Set FUNC := 'GNP ';
                /*  to examine next level down */
                                end;
until STATUS_CODE ≠ SPACES;
```

The converse exclusion search strategy as shown in figure 7-3b is identical except that "inside-a-circle" is now the discard criterion, while "outside-all-circles" becomes the present successful terminals. Note that the distance check loop may be terminated immediately if the flag ever becomes "inside-a-circle". If the loop terminates with the flag still set at the initial value, the subtree is to be discarded. A rather neat programming dodge is to use CARTAM's function-code as the flag for the various conditions. Appendix H contains the COBOL program which performs this sort of search.

Algorithm CS may also be readily extended to provide a band search, at least in Cartesian space with a Euclidian metric [$d = SQRT(x^2 + y^2)$]. A band search is defined as the retrieval of all records within a given distance of a straight line passing through an appropriately defined "GR" search rectangle. As an example in two dimensions and assuming the appropriate units, the equation of the line is given by: $Ax + By + C = 0$. Normalizing this equation by dividing by the $SQRT(A^2 + B^2)$ results in a metric function where the distance is determined by: $d = ax + by + c$. The estimator E for a square defined by a file record is then given by: $E = |a| + |b|$, which, when multiplied by the delta of the file record, gives the distance from the center of the square to a line parallel to the search line and that also passes through an appropriate corner of the square. Therefore, by replacing the two lines of algorithm CS as read:

```
Set AX := E * DELTA;
Set CA := VECTOR(lat0,lng0,lat1,lng1);
```

with:

```
Set AX := (|a| + |b|)* DELTA;
Set CA := |a*X1 + b*Y1 + c|;
```

we now have a band search for Cartesian space with a Euclidian metric.

Since CARTAM leaves the limit vectors available to the driver program at all times, a somewhat more extensive modification of algorithm CS suggests itself for a nearest neighbor search, by continually reducing the size of the search circle. As the search circle can be legitimately reduced only when a terminal record is examined, initialize the function code to 'GR L' to retrieve terminals only. Then the following algorithm will find the closest terminal record within an initial distance CZ:

```
latl := lat0 - CZ;    lngl := lng0 - CZ/cos(lat0);
lath := lat0 + CZ;    lngh := lng0 + CZ/cos(lat0);
CALL CARTAM(COMM_BLOK, USER_DATA,
            COORDS,    DELTA,     lvec, hvec);
Set function code := 'GNPL';
while STATUS_CODE = blanks do begin;
    Set CA := VECTOR(lat0,lng0,lat1,lng1);
    if CA < CZ then begin;
        Set CZ := CA;
        latl := lat0 - CZ; lngl := lng0 - CZ/cos(lat0);
        lath := lat0 + CZ; lngh := lng0 + CZ/cos(lat0);
        Save terminal information;
                    end;
    CALL CARTAM(COMM_BLOK, USER_DATA,
                COORDS,    DELTA);
                             end;
```

When this algorithm terminates, the last terminal record saved will be the terminal closest to the initial search coordinates. Conceptually, terminals in the upper right quadrant ("++" direction) are successively examined, reducing the size of the search circle (probably) each time, until the closest terminal in that quadrant is found. Then examination of the remaining quadrants proceeds very quickly.

One final example has to do with a plotting application, in particular the presentation of maps with various levels of detail upon a graphical display device. If a particular area of the world were to be presented every time maps were requested, it would be a simple matter to construct a sub-image for display and call it up from secondary storage as required. However, if the areas to be mapped are defined by limits specified at run-time along with user-determined levels of detail, the number of pre-built maps becomes prohibitive due to the geometric explosion of combinations. The obvious soultion is to build the maps upon request.

Our second example file is built in the Cartesian Index format for this purpose, containing as data the set of plottable points defining coastal and country boundaries. There are approximately 100,000 points in this file also, but this time our latitudes and longitudes are single precision floating point numbers expressed as arc radians. The terminal user-defined information contains a sequence number for its relative position along the plotted line as well as a coastal/country boundary indicator. Once the application program determines the map limits from the user for the session, CARTAM is requested to retrieve those points within the rectangle defined by those limits. Using the user-defined data stored with the terminal records, these points may then be sorted internally, plotted and displayed on the screen.

Using CARTAM to retrieve map points for construction of background maps has resulted in a drastic reduction in map preparation time. This is aptly illustrated by a comment in an internal document, STAMPS Graphics Utilities User's Manual, 1 February 1977. "Since creation of an image of a map background requires a considerable amount of time (up to five minutes CPU) it would be impractical and inefficient to build these backgrounds on-line. ... the time required to build the maps would prohibit using them on the system." While the "five minutes" refers to CPU time for an IBM System 360, Model 85, and current experience has been on a System 370, Model 3033, the same map backgrounds are now being built in roughly five seconds elapsed time. The performance has improved to the extent that pre-built maps are no longer used; in fact, as the application user desires to examine a smaller area, the map limits are recomputed and the map backgrounds are completely redone each time.

CHAPTER VIII

ASSESSMENTS AND RECOMMENDATIONS

The past few chapters have described the use of the CARTAM routine and the associated Cartesian Index File with some examples of actual applications. These examples have been limited to two dimensions, specifically latitude and longitude on the surface of the earth, but there has been no intention to imply that CARTAM is limited to two dimensions. Nor is it necessary that the coordinate values carry the same units, such as arc measure in the case of latitude and longitude. A better separation would be obtained if each of the coordinates are scaled such that the ranges of values are approximately the same, but, again, there is no hard and fast requirement imposed by CARTAM. As an example, the installation file that was described earlier can very easily be defined with three coordinates instead of two by adding a coordinate carrying a numeric representation of a category, for instance. Effectively, this would separate the installations into categorical layers which may prove extremely useful in some cases. Since CARTAM does not apply any specific metric function to the records, the number and type of coordinates is totally at the discretion of the user who may then apply whatever metric function is deemed appropriate for discrimination.

A final thought has to do with possible optimizations of the Cartesian file for large read-only applications. The file as built by repeated insertions tends to have pointer chains spread randomly over the file, which increases the number of physical retrievals from secondary storage. One possibility would be to recopy the Cartesian file once it had been completely loaded. The initially-loaded file would be read in the Get Next hierarchical sequence and copied in that order onto the final file. This would allow any searches using the 'GNP' philosophy to proceed in a monotonic manner through the final Cartesian file. The other alternative might be to recopy the initial file in such a way as to group as many nodes of the same level on the same physical record (control interval) as possible, building a many-way tree a la Knuth [8, pg 471]. The usefulness of this may be open to conjecture if the majority of the searches are small circle searches, since this type of search proceeds down a single path of the tree for several levels.

The CARTAM routine has proven itself as a very useful, generalized method to construct a multi-dimensionally-keyed file and provide extremely rapid access to desired records therein. The programs have been implemented in demonstrated efficient code and have proved themselves in a variety of complex applications. With the help of this document, additional applications of these techniques should be very straightforward with implementation in a minimum of time.

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APPENDIX A

CARTAM SOURCE

```
CARTAM   TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX    *
               MACRO DEFINITIONS'

         MACRO
         REQUATE &N
         LCLA  &I,&J,&K
         LCLC  &C
&C       SETC  'R'
&J       SETA  6
&K       SETA  2
         AIF   (T'&N EQ 'O').A
&C       SETC  '&N'
.A       AIF   ('&C' EQ 'F').GO
&K       SETA  1
&J       SETA  15
.GO      ANOP
&C.&I    EQU   &I
&I       SETA  &I+&K
         AIF   (&I LE &J).GO
         MEND

         MACRO
&LBL     ZR    &R
&LBL     SR    &R,&R
         MEND

         MACRO
&LBL     LPAGE &PG
&LBL     DS    0H
         AIF   (T'&PG EQ 'O').SKLD
         AIF   ('&PG'(1,1) NE '(').LD1
         AIF   ('&PG' EQ '(R1)').SKLD
         LR    R1,&PG(1)
         AGO   .SKLD
.LD1     L     R1,&PG
.SKLD    BAL   R14,LDPAGE
         MEND
```

```
         MACRO
&LBL     MPAGE &PG
&LBL     DS    0H
         AIF   (T'&PG EQ 'O').SKLD
         AIF   ('&PG'(1,1) NE '(').LD1
         AIF   ('&PG' EQ '(R1)').SKLD
         LR    R1,&PG(1)
         AGO   .SKLD
.LD1     L     R1,&PG
.SKLD    BAL   R14,MKPAGE
         MEND

         MACRO
         SETFUNC &M
         LCLC  &A,&C,&L
         USING SET&M.0M,R8
         AIF   ('&M' NE 'F').M1
&C       SETC  'L'
SET&M.0M MVC   0(4,R5),DELWK    SUBJECT OF EXECUTE IN RTNVALS
         AGO   .M5
.M1      ANOP
&A       SETC  '&M'
         AIF   ('&M' NE 'H').M2
SET&M.0M MVC   0(2,R5),DELWK+2 SUBJECT OF EXECUTE IN RTNVALS
         AGO   .M5
.M2      ANOP
&L       SETC  '&M'
&C       SETC  '&M'
         AIF   ('&M' NE 'E').M3
SET&M.0M MVC   0(4,R5),DELWK    SUBJECT OF EXECUTE IN RTNVALS
         AGO   .MED
.M3      AIF   ('&M' NE 'D').M4
SET&M.0M MVC   0(8,R5),DELWK    SUBJECT OF EXECUTE IN RTNVALS
         AGO   .MED
.M4      MNOTE 8,'BAD TYPE CODE'
         AGO   .ND
.M5      ANOP
SET&M.00 L     R0,PRNTDEL
         SRA   R0,1                   HALVE DELTA
         AIF   ('&M' NE 'F').MALL
         BNP   SET&M.8
         AGO   .MALLF
.MED     ANOP
SET&M.00 L&M   0,PRNTDEL
         H&M.R 0,0                    HALVE DELTA
         LT&M.R 0,0
.MALL    BZ    SHUDNVR
.MALLF   ANOP
SET&M.01 ST&L  0,PRNTDEL
SET&M.02 L&L   0,PRNTDEL  ADD OR
         EX    R3,DELSIGN      TM     QSTR0-QSTRL(R5),0
         BNO   *+6
```

```
         LN&L.R 0,0        SUBTRACT DELTA BASED ON BIT STRING
         A&A    0,COORDS@(R4,R1)
         ST&A   0,COORDS@(R4,R1)
SET&M.0  L&A    0,COORDS@(R4,R1) COORDINATE IN FILE         EI
         S&A    0,0(R4,R10) COORDINATE FROM SEARCH|ISRT     XH
         BP     SET&M.2
         BM     SET&M.1
         C&C    0,DELWK             (EI - XH) = 0
         BL     SET&M.3
         B      SET&M.4

SET&M.1  LP&L.R 0,0                 (EI - XH) < 0
         C&C    0,DELWK
         BL     SET&M.3
         OI     SETFLGS,XNOTINE     PART OF SEARCH OUTSIDE
         B      SET&M.4                     "SQUARE"

SET&M.2  EX     R3,NEGHI       OI     QSTRH-QSTRL(R5),0
         C&C    0,DELWK            (EI - XH) > 0
         BNH    SET&M.3
         OI     SETFLGS,EMPTYSET    INTERSECTION IS EMPTY
SET&M.3  OI     SETFLGS,ENOTINX     PART OF "SQUARE" OUTSIDE

SET&M.4  L&A    0,0(R4,R9)    LOW SIDE SEARCH COORDINATE    XL
         S&A    0,COORDS@(R4,R1)    FILE COORDINATE         EI
         BP     SET&M.6
         BZ     SET&M.5
         EX     R3,NEGLO      OI    QSTRL-QSTRL(R5),0
         LP&L.R 0,0                 (XL - EI) < 0
SET&M.5  C&C    0,DELWK
         BL     SET&M.7
         BER    R14
         OI     SETFLGS,XNOTINE     PART OF SEARCH OUTSIDE
         BR     R14

SET&M.6  C&C    0,DELWK
         BL     SET&M.7
         OI     SETFLGS,EMPTYSET    INTERSECTION IS EMPTY
SET&M.7  OI     SETFLGS,ENOTINX     PART OF "SQUARE" OUTSIDE
         BR     R14
         AIF    ('&M' NE 'F').ND
SET&M.8  BZ     SHUDNVR
         L      R0,PRNTDEL FULL WORD INTEGER INFINITE DELTA
         SRL    R0,1                APPEARS TO BE NEGATIVE
         B      SET&M.01
SETNTRYM EQU    SET&M.0M-SET&M.0M   OFFSET FOR EX IN RTNVALS
SETNTRY1 EQU    SET&M.00-SET&M.0M   OUTER LOOP OFFSET IN F4A
SETNTRY2 EQU    SET&M.02-SET&M.0M   INNER LOOP OFFSET IN F4A
SETNTRY3 EQU    SET&M.0-SET&M.0M    LOOP OFFSET IN INTRSECT
.ND      DROP   R8
         MEND
```

```
*  PUNCH A LINK EDITOR CONTROL CARD TO FORCE PAGE ALIGNMENT

         PUNCH '          PAGE  CARTAM'




         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX'
CARTAM   CSECT
         USING *,R15
         B     PASTID
         DC    AL1(L'ID)
ID       DC    C'CARTAM.&SYSDATE..&SYSTIME'
         PRINT NOGEN
PASTID   STM   R14,R12,12(R13)
         LR    R14,R13
         STD   F0,SAVEFPR0
         STD   F2,SAVEFPR2
         CNOP  0,4
         BAL   R13,PASTCONS
         DROP  R15
         USING *,R13
         DC    18F'0'              SAVE AREA

PARMADDR DC    A(0)
PARMCNT  EQU   PARMADDR,1

SAVEFPR0 DC    D'0'
SAVEFPR2 DC    D'0'
SETFSAVE DS    10F
         ORG   SETFSAVE
XTNDSAVE DS    F
LODESAVE DS    7F
         ORG
MASTERPG DC    A(L'FILECNTL)       RBA OF MASTER PAGE

         REQUATE
         REQUATE F

MAX#BFRS EQU   32                  MAXIMUM NUMBER OF BUFFERS
MIN#BFRS EQU   4                   MINIMUM NUMBER OF BUFFERS

SHUDNVR  ABEND 97,DUMP,STEP
STKOVFLO ABEND 24,DUMP,STEP
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX
               WORK AREA DEFINITIONS'
COMMBLOK DSECT
         USING *,R11
CBDDNAME DS    CL8         DDNAME OF FILE
CBFUNC   DS    0CL4        FUNCTION CODE
CBFUNC1  DS    C
CBFUNC2  DS    C
CBFUNC3  DS    C
CBFUNC4  DS    C
CBSTATUS DS    CL2         RETURN STATUS
CBMODE   DS    C           MODE OF ARITHMETIC
CBNORT   DS    X           NODE|TERMINAL INDICATOR
CBRBA    DS    F           RBA OF RECORD RETRIEVED|INSERTED
CBMAXUDL DS    H           MAX LENGTH OF USER DATA AREA
CBTRUUDL DS    H           TRUE LENGTH OF USER DATA
CB#GETS  DS    H           COUNTER FOR VSAM "GETS"
CB#PUTS  DS    H           COUNTER FOR VSAM "PUTS"

*        REDEFINITION IN EFFECT WHEN FUNC = "LOAD"|"OPEN"
         ORG   CBNORT
CBPAD    DS    C           USER DATA AREA PAD CHARACTER
CB#XS    DS    H           # COORDINATES
CB#BUFRS DS    H           # PAGING BUFFERS TO BE USED
         ORG




DIRECTRY EQU   0,16
RBA      EQU   0,4         RBA OF PAGE IN FRAME
FRM      EQU   4,4         FRAME CORE ADDRESS
FLGS     EQU   8,1
CNTLADDR EQU   8,4         CORE ADDRESS OF VSAM CONTROL INFO
FWD      EQU   12,4        FWD LINK ON LRU RING
```

```
FCBAREA  DSECT
         USING *,R12
FCBLABEL DS    CL8        LABEL IS FILE DDNAME
PREVFCB  DS    A          BACKWARD AND
NEXTFCB  DS    A                       FORWARD LINKS

         IFGACB DSECT=NO GENERATED ACB
         IFGRPL DSECT=NO GENERATED RPL
         DS    0D
LNACBAR  EQU   IFGRPL-IFGACB
LNRPLAR  EQU   *-IFGRPL

CISIZE   DS    F          CONTROL INTERVAL SIZE
AVSPAC   DS    F          AVAILABLE SPACE
ENDRBA   DS    F          ENDING RBA
LRECL    DS    F          LOGICAL RECORD SIZE = CISIZE-7

MVNODCS  DS    A(NODEAREA) FOR MVCL INST
         DS    F          (FLLNOD)
RCDADD   DS    A
         DS    F          (CHLDUD@)

CURRRBA  DS    F          RBA OF RCD W/ CORE ADDR IN RCDADD
BUFR@    DS    A          LOCATION AND
#SUBPOOL DS    0X
LNGBUF   DS    F          LENGTH OF PAGING AREA
PRIORT   DS    A          TOP OF LRU RING

DELWK    DS    D          EXPANDED DELTA FROM RETRIEVED RCD
PRNTDEL  DS    D          EXPANDED DELTA FOR NODEAREA

SPLTMSKS DS    0XL6       MASKS TO SEPARATE RBA'S INTO
CIMSK    DS     F         CONTROL INTERVAL RBA
DSPMSK   DS     H           AND DISPLACEMENT
         DS    H          UNUSED
LODEARGS DS    0XL6       SEPARATED RBA TO BE LOADED
LODECI   DS     F
LODEDSP  DS     H
         DS    H          UNUSED
DIREC@   DS    (MAX#BFRS)XL(L'DIRECTRY) PAGING DIRECTORY

MISCFLGS DS    XL3        MISCL FLAGS
ISRTONLY EQU   B'10000000' FILE OPENED FOR LOAD
FILEXTND EQU   B'01000000' FILE HAS BEEN EXTENDED
FRSTISRT EQU   B'00000001' FIRST INSERTION HAS NOT BEEN DONE
SENDPAD  DS    C          PAD FOR USER DATA AREA

XTRAFRM  DS    A

SETFREGS DS    XL4'80'    R3  EX MASK FOR BIT STRING
         DS    F'0'       R4  COORDINATE VECTOR INDEX
         DS    A(QSTRL)   R5  BIT STRING ADDRESS
```

```
         DS     F           R6  INDEX INCREMENT
         DS     F           R7  INDEX LIMIT VALUE
SETFADDR DS     A           R8  A(SET&M.0)
GRXL@    DS     A           R9  LOW SEARCH COORDINATES
GRXH@    DS     A           R10 HIGH SEARCH COORDINATES
GRFLAG   EQU    B'10000000' IF SET, DOING "GR" SEARCH
TRMONLY  EQU    B'01000000' IF SET, WANTS TERMINALS ONLY
TMPPRNT  DS     H           POINT IN STACK OF TEMP PARENT
STKPRNT  DS     H           POINT IN STACK OF PARENT
STKTOP   DS     H           TOP OF STACK

         DS     X'0'        ZEROES TO CLEAR BIT STRINGS
SETFLGS  DS     X           SET INTERSECTION FUNCTION FLAGS
SNGLCHLD EQU    B'10000000' INTERSECTION IS ONE CHILD ONLY
EMPTYSET EQU    B'00000100' INTERSECTION IS EMPTY
ENOTINX  EQU    B'00000010' SOME OF "SQUARE" OUTSIDE
XNOTINE  EQU    B'00000001' SOME OF SEARCH OUTSIDE
QSTRL    DS     XL64        BIT STRINGS
QSTRH    DS     XL64        OF DIFFERENCE SIGNS
QSTRO    DS     XL64

         DS     D           UNUSED
         DS     D           PERMANENT PIECE OF STACK
STACK    DS     128D
MAXSTKL  EQU    *-STACK

FILECNTL DS     XL32        FILE CONTROL INFORMATION
         ORG    FILECNTL
HIUSDRBA DS     F           CURRENT HIGH USED RBA (ISRT USES)
FLMODE   DS     C           H | F | E | D
         DS     C           UNUSED
FL#COOR  DS     H           # COORDINATES
FLLCV    DS     H           (FL#COOR)*(FLLCOOR)

DELTA@   EQU    0,2         12 BITS
RCDFLGS  EQU    1,1          4 BITS
PARENT   EQU    B'0001'     END OF TWIN CHAIN
NODRCD   EQU    B'0010'     RECORD IS A NODE
TWIN@    EQU    DELTA@+L'DELTA@,4 TWIN POINTER
COORDS@  EQU    TWIN@+L'TWIN@ START OF COORDINATE VECTOR
*QSTR@   EQU    COORDS@+(FLLCV)
QSTRLM1  DS     H           Q STRING LENGTH MINUS 1
CHLDUD@  DS     H           CHILD PTR|USER DATA DISPLACEMENT
FLLNOD   DS     H           TOTAL LENGTH OF A NODE RECORD
* = L'DELTA@+L'TWIN@+(FLLCV)+(QSTRLM1+1)+L'CHILDPTR <= 2000

*                           SO FAR 16 BYTES ARE LEFT
         ORG
NODEAREA DS     XL2000      NODE CONSTRUCTION WORKSPACE
FCBLNG   EQU    *-FCBLABEL HOPEFULLY < 4096
         ORG    *-132
RPLMSG   DS     CL132'RPL MESSAGE AREA'
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX   *
               INITIAL ENTRY'
CARTAM   CSECT
PASTCONS ST    R13,8(R14)      LINK SAVE AREAS
         ST    R14,4(R13)
         ST    R1,PARMADDR     SAVE PARAMETER LIST ADDRESS
         L     R11,0(R1)
         CLI   0(R11),0        OPTIONAL PARM COUNT PRESENT?
         BNE   PASTPC
         L     R15,0(R11)      PARAMETER COUNT
         LA    R1,4(R1)
         ST    R1,PARMADDR     STEP PAST COUNT
         L     R11,0(R1)       ADDRESS OF COMMBLOK
         B     STPCT
PASTPC   LA    R15,1           COUNT PARAMETERS
         LA    R0,5            NEED AT MOST 6
CNTPC    TM    0(R1),B'10000000'
         BO    STPCT
         LA    R1,4(R1)
         LA    R15,1(R15)
         BCT   R0,CNTPC
STPCT    STC   R15,PARMCNT
         MVC   CBSTATUS,=C'  ' INITIAL GOOD RETURN STATUS
         L     R9,=A(NOFCB)
         USING NOFCB,R9
         LA    R12,NULLABEL
FINDFCB  LR    R8,R12
         L     R12,NEXTFCB     LOOK FOR PROPER FCB
         CLC   CBDDNAME,FCBLABEL
         BH    FINDFCB
         BLR   R9            NOT ON CHAIN; GO MAKE A NEW ONE
         CLC   CBFUNC,=C'CLSE' IS ON CHAIN; R12 IS NOW BASE
         BE    CLSE
         B     CHKFUNC
         DROP  R9

         LTORG

NULLABEL DC    2F'0'           HEAD AND
         DC    A(0)
         DC    A(ENDLABEL)
ENDLABEL DC    2F'-1'          TAIL FOR FCB CHAIN
         DC    A(NULLABEL)
         DC    A(0)
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX  *
               CONVERT AN RBA TO A CORE ADDRESS'

MKPAGE   MVI   LOD5+1,X'F0'   MARK A CI AS MODIFIED
         B     LODE

LDPAGE   MVI   LOD5+1,X'00'   LOAD ONLY; WILL NOT BE CHANGED

LODE     STM   R14,R4,LODESAVE
         ST    R1,CURRRBA
         ST    R1,LODECI      RBA OF CI +
         STH   R1,LODEDSP                  DISPLACEMENT
         NC    LODEARGS,SPLTMSKS
         BZ    LERADXTO       ZERO RBA IS AN ERROR
         LA    R4,PRIORT-FWD  START AT TOP OF PRIORITY LIST
LOD1     L     R0,FWD(R4)
         LTR   R0,R0
         BZ    LOD2           CI WAS NOT IN CORE
         LR    R3,R4
         LR    R4,R0
         CLC   LODECI(3),RBA(R4)
         BNE   LOD1
LOD5     OI    FLGS(R4),*-*   MARK IF NECESSARY
         MVC   FWD(L'FWD,R3),FWD(R4) RESET LRU LIST
         MVC   FWD(L'FWD,R4),PRIORT
         ST    R4,PRIORT
         L     R1,FRM(R4)     GET CORE ADDRESS
         AH    R1,LODEDSP
         ST    R1,RCDADD
         ZR    R2
         TM    RCDFLGS(R1),NODRCD
         BNO   LOD8           TERMINAL HAS NO DELTA STORED
         TM    DELTA@(R1),B'10000000'
         BO    LOD7           STORED AS LOG2
         L     R2,DELTA@(R1)
         N     R2,=X'FFF00000' CLEAR GARBAGE
         B     LOD8
LOD7     IC    R15,DELTA@(R1) TAKE ANTILOG2
         LA    R2,1
         SLL   R2,0(R15)
LOD8     ST    R2,DELWK       STORE EXPANDED DELTA
         LM    R14,R0,LODESAVE
         LM    R3,R4,LODESAVE+20
         L     R2,TWIN@(R1)   EXIT WITH TWIN PTR IN R2
         TM    RCDFLGS(R1),PARENT
         BNOR  R14
         ZR    R2             ZERO R2 FOR END OF TWIN CHAIN
         BR    R14
```

```
LOD2     LA    R2,IFGRPL
         MODCB RPL=(R2),AREA=(*,FRM(R4)),ARG=(S,RBA(R4))
         TM    FLGS(R4),X'F0' IS IT MARKED?
         BZ    LOD4
         NI    FLGS(R4),X'0F' CLEAR MARK FLAG
         LA    R14,1
         AH    R14,CB#PUTS
         STH   R14,CB#PUTS
         PUT   RPL=(R2)        WRITE OUT MODIFIED CI

LOD4     MVC   RBA(L'RBA,R4),LODECI RBA OF CI TO READ
         LA    R14,1
         AH    R14,CB#GETS
         STH   R14,CB#GETS
         L     R0,FRM(R4)      TRY TO TELL MVS NOT TO BOTHER
         L     R1,FRM+L'DIRECTRY(R4)  PAGING IN AREA
         PGRLSE LA=(0),HA=(1)
         GET   RPL=(R2)
         B     LOD5


XTLST    EXLST LERAD=(LERADXT,A),SYNAD=(SYNADXT,A)

LERADXT0 LA    R0,16           LOGICAL ERROR EXIT
         ST    R0,CBRBA
         B     LERADXT1
LERADXT  SHOWCB RPL=(1),AREA=(S,CBRBA),LENGTH=4,FIELDS=FDBK
LERADXT1 MVC   CBSTATUS,=C'AJ'
         B     RTN

SYNADXT  MVC   RPLMSG+10(2),WTOMSG+2 PHYSICAL ERROR EXIT
         LH    R15,RPLMSG+4
         STH   R15,RPLMSG+8
         LA    R15,RPLMSG+4(R15)
         MVC   0(4,R15),WTOMSG+8
         WTO   MF=(E,RPLMSG+8) DISPLAY ERROR MESSAGE ON JES
         MVC   CBSTATUS,=C'AO'                              LOG
         B     RTN

WTOMSG   WTO   '1234',ROUTCDE=(11),DESC=(6),MF=L

         LTORG
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX  *
               PERFORM REQUESTED RETRIEVE FUNCTION'
CHKFUNC  LH    R7,FLLCV        LENGTH OF COORD VECTOR
         LH    R8,QSTRLM1      LENGTH OF Q BIT STRING - 1
         CLC   CBFUNC,=C'ISRT'
         BE    ISRT
         TM    MISCFLGS,ISRTONLY
         BO    NOTG
         L     R1,RCDADD
         ZR    R15             SHOULD BE A "G" REQUEST
         CLI   CBFUNC1,C'G'
         BH    NOTG
         BL    CHKDLCH
         CLI   CBFUNC2,C'A'
         BL    NOTG
         CLI   PARMCNT,4
         BL    SHRTLIST
         IC    R15,CBFUNC2
         IC    R15,CMDTBL(R15)
         B     NOTG(R15)

CMDTBLX  DC    64X'00'
CMDTBL   EQU   CMDTBLX-C'A'+1
         ORG   CMDTBL+C'A'    C'ABCD'
         DC    AL1(GR-NOTG,0,GC-NOTG,GD-NOTG)
         ORG   CMDTBL+C'M'    C'MNOPQR'
         DC    AL1(GM-NOTG,GN-NOTG,0,GP-NOTG,0,GR-NOTG)
         ORG   CMDTBL+C'T'
         DC    AL1(GT-NOTG)
         ORG

SHRTLIST MVC   CBSTATUS,=C'SL' TOO FEW ARGUMENTS
         B     RTN

NORCD    MVC   CBSTATUS,=C'GE'
         B     RTN

POPIT    ZR    R0          POP STACK FOR MOST "G" REQUESTS
         LH    R14,STKTOP
         AH    R14,=AL2(-L'STACK)
         BMR   R15
         STH   R14,STKTOP
         L     R0,STACK+4(R14)
         BR    R15

CHKDLCH  CLC   CBFUNC,=C'CHNG'
         BE    CHNG
         CLC   CBFUNC,=C'DLET'
         BE    DLET

NOTG     MVC   CBSTATUS,=C'AD' INVALID CODE
         B     RTN
```

```
GP        BAL   R15,POPIT       POP CHILD
          BM    NORCD
          BAL   R15,POPIT       POP TWIN
          BM    NORCD
          BAL   R15,POPIT       POP TO PARENT
          BM    GPNS
          L     R0,STACK(R14)
          B     GETIT
GPNS      L     R0,TWIN@(R1)    RAN OUT OF STACK ENTRIES
          LTR   R0,R0
          BZ    NORCD           FOLLOW TWIN CHAIN BACK UP
          TM    RCDFLGS(R1),PARENT
          BO    GETIT           HERE IT IS
          LPAGE (R0)
          B     GPNS

GT        BAL   R15,POPIT       POP CHILD OFF STACK
          BM    NORCD           THEN POP TWIN
GC        BAL   R15,POPIT       POP TOP OF STACK
          BM    NORCD
          LTR   R0,R0
          BZ    NORCD
          B     GETIT

GR        B     GRCODE          AREA SEARCH INITIALIZATION

GN        CLI   CBFUNC3,C'P'    GET NEXT
          BE    GNPCODE                   (WITHIN PARENT)
          BAL   R15,POPIT
          BNM   GN001
          TM    RCDFLGS(R1),NODRCD STACK WAS EMPTY;
          BNO   GNT                  FOLLOW CHILD CHAIN
          LH    R15,CHLDUD@
          L     R0,0(R15,R1)
GN001     LTR   R0,R0
          BZ    GNT
          CLI   CBFUNC3,C'T'    IS SUBTREE TO BE SKIPPED?
          BNE   GETIT
GNT       BAL   R15,POPIT       YES; SKIP SUBTREE
          BM    GNTNS
          LTR   R0,R0
          BZ    GNT
          B     GETIT

GNTNS     L     R0,STACK        STACK WAS EMPTY;
GNTNS1    LTR   R0,R0           FOLLOW TWIN CHAIN
          BZ    NORCD
          LPAGE (R0)
          L     R0,TWIN@(R1)
          TM    RCDFLGS(R1),PARENT
          BO    GNTNS1
          B     GETIT
```

```
GM       L     R0,MASTERPG     GET MASTER PAGE
         MVC   STKTOP,=AL2(-L'STACK)
         B     GETIT

GD       LH    R15,=AL2(-L'STACK) GET DIRECT
         LH    R14,STKTOP      CHECK STACK TO SEE
         L     R0,CBRBA         IF IT IS THERE
         XC    STKTOP,STKTOP
GDLOOP   BXLE  R14,R15,GETIT
         CL    R0,STACK(R14)
         BNE   GDLOOP
         STH   R14,STKTOP      START STACK WITH THIS RECORD

GETIT    XC GRXL@(L'GRXL@+L'GRXH@+L'TMPPRNT+L'STKPRNT),GRXL@
         LPAGE (R0)
         BAL   R15,PUSHTW      PUSH TWIN OF LATEST RECORD
         CLI   CBFUNC3,C'P'    PARENTAGE TO BE SET
         BNE   GETITNC
         STH   R14,STKPRNT     REMEMBER PARENTAGE POSITION IN
         CLI   CBFUNC4,C'L'                                STK
         BNE   GETITNC
         STH   R14,TMPPRNT
         OI    GRXH@,TRMONLY
GETITNC  BAL   R15,PUSHCH      PUSH CHILD OF LATEST RECORD
RTNVALS  L     R3,PARMADDR
         LM    R4,R5,8(R3)     A(COORDVEC,DELTA)
         L     R15,SETFADDR
         EX    0,SETNTRYM(R15)      AN MVC INST TO MOVE DELTA
         LA    R6,COORDS@(R1)
         LR    R5,R7
         MVCL  R4,R6           MOVE COORDINATE VECTOR
         L     R4,4(R3)        A(USERDATA)
         LH    R5,CBMAXUDL
         LH    R14,CHLDUD@     NOW TO MOVE USER DATA
         AR    R14,R1
         ZR    R15
         MVI   CBNORT,C'N'     INDICATE A NODE FOR STARTERS
         TM    RCDFLGS(R1),NODRCD
         BO    MVUDAT          NONE TO MOVE
         MVI   CBNORT,C'T'
         LH    R15,DELTA@(R1)  LENGTH OF USER DATA  (*16)
         SRL   R15,4               DIVIDE BY 16
MVUDAT   STH   R15,CBTRUUDL
         ICM   R15,B'1000',SENDPAD LOAD PAD CHARACTER
         MVCL  R4,R14          MOVE USER DATA AND PAD AREA
         BNL   *+8
         MVI   CBNORT,C'X'     WAS A SHORT (TRUNCATED) MOVE
RTNRBA   MVC   CBRBA,CURRRBA   RETURN RBA TO CALLER
RTN      LD    F0,SAVEFPR0
         LD    F2,SAVEFPR2
         L     R13,4(R13)
         RETURN (14,12),T,RC=0
```

```
PUSHCH   ZR     R0                ZERO TO LEFT SIDE
         ZR     R2
         TM     RCDFLGS(R1),NODRCD CHILD (IF ANY) TO RIGHT
         BNO    PUSHTW                                  SIDE
         LH     R2,CHLDUD@
         L      R2,0(R2,R1)
PUSHTW   LH     R14,STKTOP        IF PUSHING TWIN, CURRENT RBA
         CH     R14,=AL2(MAXSTKL-L'STACK) IN LEFT SIDE
         BH     STKOVFLO                   BECOMES PARENT
         ST     R0,STACK(R14)              FOR ALL ABOVE IT
         ST     R2,STACK+4(R14)            IN STACK
         LA     R14,L'STACK(R14)
         STH    R14,STKTOP
         BR     R15


POPITP   ZR     R2                POP STACK FOR GNP PROCESSING
         LH     R14,STKTOP
         CH     R14,TMPPRNT       MARKED AS TEMP PARENT?
         BNH    GNPGM                    YES
         CH     R14,STKPRNT       MARKED AS PARENT?
         BNH    NORCD                    YES
         AH     R14,=AL2(-L'STACK)
         BM     NORCD             STACK IS EMPTY
         STH    R14,STKTOP
         L      R2,STACK+4(R14)
         BR     R15

GNPGM    XC     TMPPRNT,TMPPRNT FINISHED SUBTREE
         TM     GRXH@,TRMONLY
         BNO    NORCD
         NI     GRXH@,X'FF'-TRMONLY
         MVC    CBSTATUS,=C'GM'
         B      RTN


GRCODE   CLI    PARMCNT,6         AREA SEARCH SETUP
         BL     SHRTLIST
         L      R15,PARMADDR
         MVC    GRXL@(L'GRXL@+L'GRXH@),16(R15) ADDRS OF LIMIT
         MVI    GRXH@,GRFLAG                           VECTORS
         XC     TMPPRNT(L'TMPPRNT+L'STKPRNT),TMPPRNT
         CLI    CBFUNC4,C'L'
         BNE    *+8
         OI     GRXH@,TRMONLY
         MVI    SETFLGS,0
         MVC    STKTOP,=AL2(-L'STACK)
         LPAGE  MASTERPG          START WITH MASTER PAGE
         B      GNP4
```

```
GNPCODE  MVI    SETFLGS,0
         BAL    R15,POPITP
         CLI    CBFUNC4,C'L'
         BNE    GNP0
         TM     GRXH@,TRMONLY
         BO     GNP2
         STH    R14,TMPPRNT     LAST RCD READ IS TO BE MARKED
         OI     GRXH@,TRMONLY   TO RETRIEVE ALL TERMINALS OF
         B      GNP2                                   SUBTREE

GNP0     CLI    CBFUNC4,C'T'    IS CHILD SUBTREE TO BE
         BNE    GNP2                                DISCARDED?
GNP1     MVI    SETFLGS,0
GNPOC0   BAL    R15,POPITP
GNP2     LTR    R0,R2
         BZ     GNP1
         LPAGE  (R0)
         TM     SETFLGS,SNGLCHLD LOOKING FOR A SINGLE CHILD?
         BNO    GNP4

         LA     R14,COORDS@(R7,R1)
         EX     R8,CLQRL             CLC    0(0,R14),QSTRL
         BL     GNP2            NOT YET
         BH     GNP1            MISSED IT
         ZR     R2              FOUND IT; NEED NO MORE

GNP4     BAL    R15,PUSHTW
         MVI    SETFLGS,0
         TM     GRXH@,GRFLAG    GR PROCESSING?
         BNO    GNP5

         BAL    R15,INTRSECT
         B      GNP1         +0 EMPTY INTERSECTION; DISCARD
         CLC    QSTRL,QSTRH  +4
         BNE    *+8
         OI     SETFLGS,SNGLCHLD

GNP5     BAL    R15,PUSHCH
         TM     RCDFLGS(R1),NODRCD
         BNO    RTNVALS         RETURN ALL TERMINALS
         TM     SETFLGS,SNGLCHLD IF ONLY ONE CHILD OF
         BO     GNPOC0          INTEREST, GET IT IMMEDIATELY
         TM     GRXH@,TRMONLY
         BO     GNP1            CALLER WANTS TERMINAL ONLY
         B      RTNVALS
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX
               INSERT FUNCTION'
CLQRL    CLC   0(0,R14),QSTRL
NEGLO    OI    QSTRL-QSTRL(R5),0
NEGHI    OI    QSTRH-QSTRL(R5),0
DELSIGN  TM    QSTRO-QSTRL(R5),0



ISRT     CLI   PARMCNT,3
         BL    SHRTLIST
         L     R15,PARMADDR
         L     R6,4(R15)           ADDRESS OF USER DATA
         L     R4,8(R15)           ADDRESS OF COORDINATE VECTOR
         LA    R5,0(R4)
         STM   R4,R5,GRXL@
         TM    CBTRUUDL,B'10000000'
         BO    ISRT07              UD TOO LONG
         LH    R15,CBTRUUDL
         AH    R15,CHLDUD@
         SLL   R15,1               TOTAL LENGTH MUST BE LESS THAN
         C     R15,LRECL           HALF OF THE LRECL
         BNH   ISRT08
ISRT07   MVC   CBSTATUS,=C'IU' USER DATA TOO LONG
         B     RTN

ISRT08   TM    MISCFLGS,FRSTISRT
         BNO   ISRT09
         NI    MISCFLGS,X'FF'-FRSTISRT
         LPAGE MASTERPG            FIRST INSERTION ON A LOAD
         BAL   R15,CALCQSTR
         NOP   0
         B     F6NEWTRM

ISRT09   BAL   R15,POPIT           TOP OF STACK IS PROBABLY ZEROS
ISRT10   BAL   R15,POPIT
         BNM   ISRT12
         ZR    R14
         STH   R14,STKTOP
ISRT12   L     R9,STACK-L'STACK(R14) CLIMB PARENT DIRECTION
         LPAGE (R9)                UNTIL NODE COMPLETELY COVERS
         BAL   R15,INTRSECT              NEW COORDS
         B     ISRT10      +0
         TM    SETFLGS,ENOTINX +4
         BNO   ISRT10
*        B     B2
```

```
B2       LM    R2,R5,MVNODCS
         MVCL  R2,R4           REMEMBER CONTENTS OF NODE
         MVC   PRNTDEL,DELWK   AS PROBABLE PARENT
         LH    R10,STKTOP
         BAL   R15,PUSHCH
         LTR   R9,R2
         BZ    SHUDNVR

C3       LPAGE (R9)           LOOK FOR CHILD IN SAME DIRECTION
         LA    R14,COORDS@(R7,R1) AS NEW COORDINATES
         EX    R8,CLQRL             CLC       0(0,R14),QSTRL
         BH    F6NEWTRM        MISSED IT
         BE    QE
         ST    R9,STACK(R10)   NOT YET
         ST    R2,STACK+4(R10)        (PUSH TWIN)
         LTR   R9,R2
         BNZ   C3
         B     F6NEWTRM        NOT ON CHAIN INSERT TERMINAL

QE       LA    R14,COORDS@+NODEAREA(R7)
         EX    R8,MVQRL
         BAL   R15,CALCQSTR    ARE NEW COORDS INSIDE RECORD?
         NOP   0
         TM    SETFLGS,EMPTYSET+ENOTINX
         BZ    XEMATCH         MATCHING POINT COORDS
         BO    F40             NO; EMPTY INTERSECTION
         ST    R9,STACK(R10)   YES; TOTALLY INSIDE
         ST    R2,STACK+4(R10)
         B     B2



CALCQSTR LA    R14,QCALC       CALC A FULL Q BIT STRING
         B     INTRO

INTRSECT LA    R14,INTRTEST    EXIT IMMED. IF NO INTERSECTION
INTRO    STM   R3,R10,SETFSAVE
         LM    R3,R10,SETFREGS
   MVC   SETFLGS(L'SETFLGS+L'QSTRL+L'QSTRH+L'QSTRO),SETFLGS-1
         B     SETNTRY3(R8)
INTRTEST TM    SETFLGS,EMPTYSET
         BO    INTREXIT        EXIT TO +0 IF EMPTY
QCALC    SRA   R3,1
         BNZ   INTRLOOP
         LA    R3,B'10000000' NEXT BYTE ON Q STRING
         LA    R5,1(R5)
INTRLOOP BXLE  R4,R6,SETNTRY3(R8)
         LA    R15,4(R15)     EXIT TO +4 IF FULL LOOP WAS RUN
INTREXIT LM    R3,R10,SETFSAVE
         BR    R15
```

```
F40      STM   R1,R10,SETFSAVE
         MVC   TWIN@+NODEAREA,TWIN@(R1)
         LA    R14,COORDS@+NODEAREA(R7)
         EX    R8,MVQLR
         LA    R1,COORDS@(R1)
         ST    R1,GRXL@
         LA    R1,NODEAREA     NODEAREA HOLDS NEW NODE INFO
         LM    R6,R10,SETFREGS+12

F4A      MVC   QSTRO,QSTRL
         MVC   SETFLGS(L'SETFLGS+L'QSTRL+L'QSTRH),SETFLGS-1
         LM    R3,R5,SETFREGS
         BAL   R14,SETNTRY1(R8)  ADJUST COORDS IN NODEAREA
         SRA   R3,1              AND CALCULATE Q'S
         BNZ   F4B
         LA    R3,B'10000000'
         LA    R5,1(R5)
F4B      BXLE  R4,R6,SETNTRY2(R8)
         CLC   QSTRL,QSTRH
         BE    F4A             STILL SAME Q, ADJUST AGAIN
         ST    R10,GRXL@       RESET GRXL@
         CLI   SETNTRY1+L'SETF00(R8),X'8A' "SRA" OPCODE?
         BNE   F4D
         L     R14,PRNTDEL
         LH    R15,=XL2'7F00' CALC LOG2(DELTA)
F4C      LA    R15,X'100'(R15)
         SRA   R14,1
         BNZ   F4C
         STH   R15,PRNTDEL
F4D      MVC   DELTA@(2,R1),PRNTDEL
         LM    R1,R10,SETFSAVE QSTRL IS FOR LAST RECORD READ
         B     F5NEWNOD        QSTRH IS FOR NEW TERMINAL


XEMATCH  TM    RCDFLGS(R1),NODRCD COORDS MATCH W/ DELTA = 0
         BO    XEMATCH0
         LM    R2,R5,MVNODCS   RECORD IS A TERMINAL;
         MVCL  R2,R4           NEED A PARENT NODE W/ DELTA
         XC    DELTA@+NODEAREA,DELTA@+NODEAREA    OF ZERO
```

```
F5NEWNOD OI     RCDFLGS+NODEAREA,NODRCD
         LH     R1,FLLNOD        LENGTH OF A NODE
         BAL    R14,XTNDSLOT
         CLC    QSTRL,QSTRH
         BH     F6NEWTRM         NEW TERMINAL GOES FIRST
         BE     F6MCHTRM         IF EQUAL, MUST BE DUP COORD
         L      R15,STACK+4(R10) NEW TERMINAL GOES SECOND
         ST     R15,STACK(R10)
         B      F6NEWTRM

XEMATCHO ST     R9,STACK(R10)    RECORD IS A NODE W/ DUP COORD
         ST     R2,STACK+4(R10)  CHILDREN
         LH     R10,STKTOP
         BAL    R15,PUSHCH

F6MCHTRM L      R0,STACK+4(R10)  ON DUP COORDS, CHCK USER DATA
F6MCHLP  LPAGE  (R0)
         LH     R15,CBTRUUDL
         LR     R14,R6
         LR     R5,R15
         LH     R4,CHLDUD@
         AR     R4,R1
         CLCL   R4,R14
         BE     IISTAT          DUPLICATE RECORDS; NO INSERTION
         ST     R0,STACK(R10)
         LTR    R0,R2
         BNZ    F6MCHLP

F6NEWTRM LH     R1,CBTRUUDL
         AH     R1,CHLDUD@       TOTAL LENGTH OF A TERMINAL
         MVI    RCDFLGS+NODEAREA,0
         MVO    DELTA@+NODEAREA,CBTRUUDL USER DATA AREA LNGTH
         LA     R4,COORDS@+NODEAREA
         LR     R5,R7
         L      R2,GRXH@
         LR     R3,R5
         MVCL   R4,R2            MOVE COORDINATE VECTOR IN
         EX     R8,MVQNH             MVC          0(0,R4),QSTRH
         BAL    R14,XTNDSLOT
         LH     R5,CBTRUUDL      R4 IS ALREADY SET
         LR     R7,R5
         MVCL   R4,R6            MOVE USER DATA IN
         B      RTNRBA

IISTAT   MVC    CBSTATUS,=C'II'
         B      RTNRBA


MVQRL    MVC    0(0,R14),QSTRL
MVQLR    MVC    QSTRL(0),0(R14)
MVQNH    MVC    0(0,R4),QSTRH
```

```
XTNDSLOT ST     R14,XTNDSAVE
         OI     MISCFLGS,FILEXTND
         L      R4,HIUSDRBA      NEXT AVAILABLE RBA
         LH     R5,DSPMSK
         NR     R5,R4
         AR     R5,R1
         C      R5,LRECL         ROOM IN CI?
         BNH    XTND0            YES
         LR     R5,R1            NO,
         N      R4,CIMSK             STEP TO NEXT CI
         AL     R4,CISIZE
XTND0    AR     R1,R4
         ST     R1,HIUSDRBA      NEW AVAILABLE RBA
         LH     R10,STKTOP       IF DOING ISRT, STACK
         CH     R10,=AL2(L'STACK) SHOULD NEVER HAVE < 1 ENTRY
         BL     SHUDNVR
         L      R1,STACK-L'STACK(R10)
         ST     R4,STACK-L'STACK(R10)  NEW RECORD GOES TO LEFT
         LTR    R1,R1                                     SIDE
         BZ     XTND1
         MPAGE  (R1)             INSERT NEW RECORD ON TWIN CHAIN
         MVC    TWIN@+NODEAREA,TWIN@(R1)
         ST     R4,TWIN@(R1)
         TM     RCDFLGS(R1),PARENT
         BNO    XTND2
         NI     RCDFLGS(R1),X'FF'-PARENT RCD JUST LINKED TO
         OI     RCDFLGS+NODEAREA,PARENT WAS END OF TWIN CHAIN
         B      XTND2
```

```
XTND1    MPAGE  STACK-2*L'STACK(R10) INSERT NEW RECORD AS
         LH     R14,CHLDUD@          FIRST CHILD OF PARENT
         L      R2,0(R14,R1)
         ST     R4,0(R14,R1)
         LA     R14,NODEAREA
         ST     R2,TWIN@(R14)

XTND2    TM     RCDFLGS+NODEAREA,NODRCD
         BNO    XTND3
         LH     R14,CHLDUD@
         ST     R2,NODEAREA(R14)
         MPAGE  (R2)
         MVC    TWIN@+NODEAREA,TWIN@(R1)
         ST     R4,TWIN@(R1)
         TM     RCDFLGS(R1),PARENT
         BNO    *+8
         OI     RCDFLGS+NODEAREA,PARENT
         OI     RCDFLGS(R1),PARENT
         LA     R14,COORDS@(R7,R1)
         EX     R8,MVQRL             MVC      0(0,R14),QSTRL

XTND3    ST     R2,STACK-L'STACK+4(R10)
         LA     R1,NODEAREA
         BAL    R15,PUSHCH
         MPAGE  (R4)             LOAD AND MARK NEW CI
         L      R15,LRECL
         L      R14,PRIORT
         L      R14,FRM(R14)
         AR     R14,R15          POINT AT AND THEN
         MVI    0(R14),0        ADJUST VSAM CONTROL INFORMATION
         STH    R5,1(R14)
         STH    R5,3(R14)
         SR     R15,R5
         STH    R15,5(R14)
         LM     R2,R5,MVNODCS
         TM     RCDFLGS+NODEAREA,NODRCD
         BNO    *+6
         LR     R5,R3            FULL LENGTH IF NODE
         MVCL   R4,R2
         L      R14,XTNDSAVE
         BR     R14
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX  *
               CHANGE|DELETE FUNCTIONS'
CHNG     CLI   PARMCNT,3
         BL    SHRTLIST
         CLC   CBRBA,CURRRBA  MUST HAVE JUST BEEN RETRIEVED
         BNE   CHNGX
         TM    RCDFLGS(R1),NODRCD
         BO    CHNGX          CAN'T CHANGE DATA ON A NODE
         L     R9,PARMADDR
         L     R6,8(R9)
         LR    R3,R7
         LA    R2,COORDS@(R1)
         CLCL  R2,R6      ENSURE COORDINATES WEREN'T CHANGED
         BNE   CHNGX
         LH    R5,DELTA@(R1)
         SRL   R5,4
         L     R6,4(R9)
         LH    R7,CBTRUUDL
         CLR   R7,R5          CHECK LENGTH
         BH    CHNGX
         MPAGE  CBRBA
         LH    R4,CHLDUD@
         AR    R4,R1
         ICM   R7,B'1000',SENDPAD
         MVCL  R4,R6          REPLACE USER DATA FIELD
         B     RTN

CHNGX    MVC   CBSTATUS,=C'CX'
         B     RTN

DLETX    MVC   CBSTATUS,=C'DX'
         B     RTN

DLET     L     R6,CBRBA
         CL    R6,MASTERPG    CAN'T DELETE MASTER RECORD
         BNH   DLETX
         CL    R6,CURRRBA     MUST HAVE BEEN JUST RETRIEVED
         BNE   DLETX
         XC    CBRBA,CBRBA
         LH    R9,CHLDUD@
         MVC   RCDFLGS+NODEAREA,RCDFLGS(R1)  SAVE FLAG
         L     R3,TWIN@(R1)       AND TWIN POINTER
         LH    R10,STKTOP
         SH    R10,=AL2(3*L'STACK)
         BNM   DLET03

         ZR    R10            PARENT NOT IN STACK
DLET01   L     R0,TWIN@(R1)   WALK TWIN CHAIN TO FIND IT
         TM    RCDFLGS(R1),PARENT
         BO    DLET02         FOUND IT
         LPAGE (R0)
         B     DLET01
```

```
DLET02   ST    R0,STACK(R10)

DLET03   LPAGE STACK(R10)      STARTING AT PARENT OF "X",
         ST    R2,STACK+4(R10)  (ENSURE PRNT'S TWIN IN STACK)
         LA    R14,COORDS@(R7,R1)  LOOK FOR PREDECESSOR
         EX    R8,MVQLR              MVC   QSTRL(0),0(R14)
         MVC   QSTRH(TWIN@+L'TWIN@),0(R1)  SAVE Q, TWIN PTR,
         CL    R6,0(R9,R1)                                FLG
         BNE   DLETTWIN


DLETCHLD MPAGE STACK(R10)      PARENT WAS PREDECESSOR; MARK
         ST    R3,0(R9,R1)     SUCCESSOR IS NOW FIRST CHILD
         LPAGE (R3)
         LTR   R2,R2
         BZ    LONETWIN        WHOOPS; LONE REMAINING CHILD

         ST    R3,STACK+L'STACK+4(R10)  DELETED RECORD WAS
         ZR    R0           FIRST OF ONLY TWO CHILDREN.  LEAVE
         ST    R0,STACK+L'STACK(R10)  STACK W/ SUCCESSOR AS
         LA    R15,2*L'STACK(R10)  FIRST (UNRETRIVED) CHILD
         STH   R15,STKTOP               OF PARENT OF "X"
         B     RTN


DLETTWIN L     R0,0(R9,R1)  PARENT NOT IMMEDIATE PREDECESSOR
         LR    R4,R0           REMEMBER FIRST CHILD
DLETT1   LPAGE (R0)            WALK TWIN CHAIN
         CLR   R2,R6
         BE    DLETT2
         LTR   R0,R2
         BNZ   DLETT1
DLETNVR  ABEND 95,DUMP,STEP


DLETT2   ST    R0,STACK+L'STACK(R10)  SAVE IN LEFT SIDE OF
         MPAGE (R0)                                 STACK
         ST    R3,TWIN@(R1)
         TM    RCDFLGS+NODEAREA,PARENT WAS "X" ON END OF
         BNO   DLETT3                               CHAIN?
         OI    RCDFLGS(R1),PARENT
         ZR    R3
         CLR   R4,R0           IS PREDECESSOR FIRST CHILD?
         BE    LONECHLD        YES
DLETT3   ST    R3,STACK+L'STACK+4(R10)  LEAVE STACK W/
         ZR    R0        PREDECESSOR IN PLACE OF "X", BUT SHOW
         ST    R0,STACK+2*L'STACK(R10)  NO CHILD AS CHILD OF
         ST    R0,STACK+2*L'STACK+4(R10)  PRED(X) HAS BEEN
         LA    R15,3*L'STACK(R10)     PRESENTED EARLIER.
         STH   R15,STKTOP
         B     RTN
```

```
*                                  RECORD DELETED WAS ONE OF ONLY TWO
LONETWIN MPAGE  (R3)                                      ON CHAIN
         ZR     R4                 PREDECESSOR IS PARENT

LONECHLD NI     RCDFLGS(R1),X'FF'-PARENT REPLACE
         MVC    TWIN@(L'TWIN@,R1),TWIN@+QSTRH TWIN POINTER,
         NI     RCDFLGS+QSTRH,PARENT
         OC     RCDFLGS(L'RCDFLGS,R1),RCDFLGS+QSTRH ITS FLAG,
         LA     R14,COORDS@(R7,R1)                   AND Q STRING
         EX     R8,MVQRL             MVC    0(0,R14),QSTRL
         L      R5,STACK(R10)   RBA OF PARENT TO BE REPLACED
         AH     R10,=AL2(-L'STACK)
         BNM    LONE03

         ZR     R10
LONE01   L      R0,TWIN@(R1)
         TM     RCDFLGS(R1),PARENT
         BO     LONE02
         LPAGE  (R0)
         B      LONE01
LONE02   ST     R0,STACK(R10)

LONE03   L      R0,STACK(R10)
         LPAGE  (R0)
         ST     R2,STACK+4(R10) ENSURE PARENT'S TWIN IN STACK
         CL     R5,0(R9,R1)
         BE     LONE10          REPLACED PARENT FIRST ON CHAIN
         L      R0,0(R9,R1)
         LA     R9,TWIN@

LONE05   LPAGE  (R0)       REPLACED PARENT IS ALONG TWIN CHAIN
         CLR    R5,R2
         BE     LONE10
         LTR    R0,R2
         BNZ    LONE05
         B      DLETNVR

LONE10   ST     R4,STACK+L'STACK(R10) STORE PREDECESSOR IN
         LTR    R4,R4                                STACK
         BNZ    LONE11
         ST     R3,STACK+L'STACK+4(R10) PRED(X) IS A PARENT
         LA     R15,2*L'STACK(R10)  SUCCESSOR IS NON-NULL
         LR     R4,R3
         B      LONE12

LONE11   ST     R3,STACK+2*L'STACK(R10) PRED(X) IS NON-NULL
         ST     R3,STACK+2*L'STACK+4(R10) SUCC IS NULL
         LA     R15,3*L'STACK(R10)
LONE12   STH    R15,STKTOP
         MPAGE  (R0)
         ST     R4,0(R9,R1)     STORE AS CHILD OR TWIN
         B      RTN
```

```
         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX    *
               MODE DEPENDENT "SET" FUNCTIONS'
         LTORG



         PUSH  PRINT
         PRINT GEN


         SETFUNC F


         SETFUNC H


         SETFUNC E


         SETFUNC D

         POP   PRINT




         TITLE '    PROGRAM TO HANDLE N-DIMENSIONAL INDEX    *
               INITIALIZATION SECTION'
         USING NOFCB,R9
NOFCB    CLC   CBFUNC,=C'CLSE' DID NOT FIND
         BE    RTN
         CLC   CBFUNC,=C'OPEN'
         BE    NEWFCB
         CLC   CBFUNC,=C'LOAD'
         BNE   NOTG             INVALID FUNCTION CODE
         LH    R2,CB#XS
         CH    R2,=AL2(8*L'QSTRL)
         BNH   CHKMODE
         MVC   CBSTATUS,=C'AX'
         B     RTN
```

```
CHKMODE  CLI   CBMODE,C'D'
         BL    MODEERR          ERROR
         CLI   CBMODE,C'H'
         BH    MODEERR          ERROR
         CLI   CBMODE,C'G'
         BNE   NEWFCB
MODEERR  MVC   CBSTATUS,=C'AM'
         B     RTN

NEWFCB   LH    R7,SPFCBLNG+2
         GETMAIN RU,LV=(R7),BNDRY=PAGE,SP=SUBPOOL#
         LR    R6,R1
         LA    R14,CBDDNAME
         LA    R15,L'CBDDNAME
         MVCL  R6,R14
         ST    R1,NEXTFCB-FCBAREA(R8)
         ST    R1,PREVFCB
         ST    R12,NEXTFCB-FCBAREA(R1)
         LR    R12,R1
         ST    R8,PREVFCB
         GENCB BLK=ACB,DDNAME=(*,CBDDNAME),EXLST=XTLST,        *
               LENGTH=LNACBAR,WAREA=(S,IFGACB), GEN AN ACB *
               MAREA=(S,RPLMSG),MLEN=L'RPLMSG, FOR FILE        *
               MACRF=(CNV,DIR,ICI,IN,OUT,UBF)
         CLC   CBFUNC,=C'OPEN'
         BE    OPENINIT
         MVI   MISCFLGS,ISRTONLY+FRSTISRT
         MVC   FLMODE,CBMODE
         STH   R2,FL#COOR
         ZR    R3
         IC    R3,CBMODE
         SLL   R3,3             MODE CHARACTER * 8
         LH    R4,MODETBL-8*C'D'+6(R3) INFINITE DELTA/FLAGS
         STH   R4,DELTA@+NODEAREA   FOR MASTER RECORD
         LH    R4,MODETBL-8*C'D'+4(R3) LENGTH OF COORDINATE
         MH    R4,FL#COOR
         STH   R4,FLLCV            LENGTH OF COORDINATE VECTOR
         BCTR  R2,0             FLOOR((#X+7)/8) - 1
         SRL   R2,3             = FLOOR((#X-1)/8)
         STH   R2,QSTRLM1       LENGTH OF Q BIT STRING MINUS 1
         LA    R5,L'DELTA@+L'TWIN@+1(R4,R2)
         STH   R5,CHLDUD@     DISPLACEMENT TO CHILD|USER DATA
         LA    R5,4(R5)
         CH    R5,=AL2(L'NODEAREA)
         BNH   STLNOD
AXERR    MVC   CBSTATUS,=C'AX'
         B     CLSE3
```

```
STLNOD   STH   R5,FLLNOD        FINAL NODE LENGTH
         LA    R5,L'FILECNTL(R5)
         ST    R5,HIUSDRBA
         XC    XTNDSAVE,XTNDSAVE
         LA    R8,CARTINIT
         BAL   R10,OPNINIT
         CLC   HIUSDRBA,LRECL
         BH    AXERR            LRECL TOO SMALL
         LM    R4,R6,CISIZE
         LTR   R6,R6
         BNZ   CLSINIT
         BCTR  R5,0            EMPTY DATA SET; PREFORMAT CI'S.
         L     R2,PRIORT
         MODCB RPL=PRPL,AREALEN=(*,CISIZE),                        *
               RECLEN=(*,LRECL),AREA=(*,FRM(R2))

INITLOOP PUT   RPL=PRPL
         BXLE  R6,R4,INITLOOP

CLSINIT  CLOSE CARTINIT         NOW DOWN TO WORK WITH REAL ACB
         LA    R8,IFGACB
         BAL   R6,MODOPN
         L     R3,MASTERPG
         MPAGE (R3)             INITIALIZE MASTER PAGE
         LR    R4,R1
         SR    R4,R3
         L     R5,LRECL
         LA    R14,FILECNTL
         L     R15,HIUSDRBA
         MVCL  R4,R14
         B     FININIT

MODETBL  DC    A(SETDOM),H'08',XL2'7F83' D
         DC    A(SETEOM),H'04',XL2'7F83' E
         DC    A(SETFOM),H'04',XL2'9F03' F
         DC    2F'0'               G
         DC    A(SETHOM),H'02',XL2'8F03' H
```

```
*                               OPEN AN EXISTING FILE
OPENINIT LA     R8,IFGACB
         BAL    R10,OPNINIT
         L      R3,MASTERPG
         LPAGE  (R3)
         LR     R4,R1
         SR     R4,R3
         MVC    FILECNTL,0(R4) BRING IN FILE CONTROL INFO
         MVC    CBMODE,FLMODE  RETURN MODE
         MVC    CB#XS,FL#COOR                & # COORDS
FININIT  MVC    SENDPAD,CBPAD  SAVE USER AREA PAD CHARACTER
         ST     R3,STACK-L'STACK MASTER PAGE RBA IN PERM STK
         MVC    STACK-L'STACK+4(L'TWIN@),TWIN@(R1)
         BAL    R15,PUSHCH
         ZR     R15
         IC     R15,FLMODE
         SLL    R15,3
         LA     R3,B'10000000' PRESET REGS FOR "SET" FUNCTION
         ZR     R4                      INDEX
         LA     R5,QSTRL                A(Q STRING)
         LH     R6,MODETBL-8*C'D'+4(R15) INDEX STEP
         LH     R7,FLLCV
         BCTR   R7,0                    INDEX LIMIT
         L      R8,MODETBL-8*C'D'(R15) A(MODE SPECIFIC CODE)
         STM    R3,R8,SETFREGS
         LA     R2,NODEAREA         A(NODEAREA)
         LH     R3,FLLNOD           L'NODE
         L      R4,RCDADD           A(CURRENT RECORD)
         LH     R5,CHLDUD@     L'NODE W/O CHLD PTR OR USER DATA
         STM    R2,R5,MVNODCS  PRESET VALUES FOR MVCL INSTRS
         B      RTN


MODOPN   MODCB ACB=(R8),DDNAME=(*,CBDDNAME)
         OPEN   ((R8))
         LTR    R15,R15
         BZR    R6
        SHOWCB ACB=(R8),AREA=(S,CBRBA),LENGTH=4,FIELDS=ERROR
         MVC    CBSTATUS,=C'AI'
         B      CLSE3
```

```
OPNINIT  BAL    R6,MODOPN
         SHOWCB ACB=(R8),AREA=(S,CISIZE),LENGTH=12,             *
               FIELDS=(CINV,AVSPAC,ENDRBA)
         L      R6,CISIZE
         BCTR   R6,0
         STH    R6,DSPMSK        RBA DISPLACEMENT MASK
         L      R14,ENDLABEL
         XR     R14,R6
         ST     R14,CIMSK        1'S COMPLEMENT OF DSPMSK
         SH     R6,=H'6'
         ST     R6,LRECL
         LH     R0,CB#BUFRS      LOAD # BUFFER PAGES BEING REQ.
         XC     CB#GETS(L'CB#GETS+L'CB#PUTS),CB#GETS
         CH     R0,*+10
         BNH    *+8
         LA     R0,MAX#BFRS
         MH     R0,CISIZE+2
         ST     R0,PRNTDEL+4     MAXIMUM AMOUNT OF CORE REQ.
         LA     R0,MIN#BFRS
         MH     R0,CISIZE+2
         ST     R0,PRNTDEL       MINIMUM AMOUNT OF CORE REQ.
         LA     R5,PRNTDEL
         LA     R3,BUFR@
         GETMAIN VU,LA=(R5),A=(R3),BNDRY=PAGE,SP=SUBPOOL#


         L      R1,BUFR@
         L      R14,CISIZE
         L      R15,LNGBUF
         MVI    #SUBPOOL,SUBPOOL#
         SR     R15,R14
         AR     R15,R1
         LA     R3,DIREC@
         ST     R3,PRIORT
         L      R0,ENDLABEL      LOAD A MINUS 1

SETFRM   LR     R4,R3            INITIALIZE PAGING DIRECTORY
         LA     R2,0(R6,R1)      (R1) + (LRECL)
         LA     R3,L'DIRECTRY(R4)
         STM    R0,R3,RBA(R4)
         BXLE   R1,R14,SETFRM
         XC     FWD(4,R4),FWD(R4) CLEAR LAST LINK
         ST     R1,FRM(R3)       STORE IN XTRAFRM FOR PGRLSE
         GENCB  BLK=RPL,ACB=(S,IFGACB), GENERATE AN RPL          *
               LENGTH=LNRPLAR,WAREA=(S,IFGRPL),                   *
               MSGAREA=(S,RPLMSG),MSGLEN=L'RPLMSG,                *
               AREALEN=(*,CISIZE),                                *
               OPTCD=(CNV,DIR,SYN,NUP)
         BR     R10
```

```
CLSE     MVC   CBRBA,HIUSDRBA
         TM    MISCFLGS,FILEXTND
         BNO   CLSE0
         MPAGE MASTERPG
         S     R1,MASTERPG
         MVC   HIUSDRBA-FILECNTL(L'HIUSDRBA,R1),HIUSDRBA
CLSE0    LA    R4,IFGRPL
         L     R2,PRIORT
CLSE1    TM    FLGS(R2),X'F0'
         BZ    CLSE2
         MODCB RPL=(R4),AREA=(*,FRM(R2)),ARG=(S,RBA(R2))
         NI    FLGS(R2),X'0F'
         PUT   RPL=(R4)          WRITE OUT ANY MARKED CI'S
CLSE2    L     R2,FWD(R2)
         LTR   R2,R2
         BNZ   CLSE1

         LA    R4,IFGACB
         CLOSE ((R4))
CLSE3    L     R0,LNGBUF
         LTR   R0,R0
         BZ    CLSE4
         L     R1,BUFR@
         FREEMAIN R,A=(1),LV=(0)
CLSE4    LM    R14,R15,PREVFCB
         ST    R14,PREVFCB-FCBAREA(R15)
         ST    R15,NEXTFCB-FCBAREA(R14)
         L     R0,SPFCBLNG
         FREEMAIN R,A=(R12),LV=(0)
         B     RTN


CARTINIT ACB   MACRF=(ADR,SEQ,NCI,OUT,NUB),EXLST=XTLST
PRPL     RPL   ACB=CARTINIT,OPTCD=(ADR,SEQ,NUP,MVE),          *
               ARG=XTNDSAVE


SUBPOOL# EQU   17                SUB POOL NUMBER
SPFCBLNG DC    AL1(SUBPOOL#),AL3(FCBLNG)


         LTORG
         END
```

APPENDIX B

Subroutine VECTOR

VECTOR is a subroutine written as an implementation of the Schrieter-Thomas method to compute the great elliptic distance and normal section azimuth between two sets of geodetic coordinates on a selected spheroid. The method was obtained from ACIC Technical Report Number 80, "Geodetic Distance and Azimuth Computations for Lines over 500 Miles." The following comments were extracted from that report concerning "Types of Positions".

> If the results of a distance and azimuth computation are to have any meaning, the terminal points used as basic data must be geodetically related, i.e., the end points must be derived from field measurements originating from a fixed point and computed along a common surface (ellipsoid). The starting point is usually defined in terms of latitude and longitude, either astronomical or geodetic, and the ellipsoid by the parameters a and b. If the initial point is fixed astronomically, the surfaces have what is known as an astro-orientation. Geometrically, this means that the geoid and ellipsoid surface coincide at that point and the fixed starting position is common to both surfaces. To the geodisist it means that the normal to the ellipsoid coincides with the local vertical at that point and the components of the deflection of the vertical are zero. The astro-geodetic orientation differs from the preceding in that it compensates for the surface departure by correcting the angles between the geometrical normals and the true local verticals.
>
> Positions on the earth's surface defined with respect to such initial quantities form a geodetic system or datum. Those derived from different datums are unrelated and consequently are unusable for inverse computations. The results would be in error and the magnitude of the error would correspond to the effect of the differences in the intial quantities of their datum. Certainly, accurate distance and azimuth cannot

be expected if the terminal points of the line are referred to different origins and possibly computed along different surfaces of unequal size.

Generally, the positions available for an inverse computation are of three types:

a. Geodetic positions such as described above.

b. Astronomic positions, latitude and longitude of which have been derived instrumentally by direct observations of celestial bodies.

c. Map positions obtained from cartographic sources.

Type a. are the most accurate although one very seldom finds two points as widely separated as 6000 miles referred to the same datum. The second type, b., astronomic points, refer to positions on the geoid and should not be used since the geoid is not a geometrical surface. To use these for computational purposes is to assume that the two surfaces are coincident and the definition of each point identical on both surfaces. This assumption could easily result in distance errors as large as two kilometers which are as likely to occur on 500 mile lines as for the 6000 mile lines.

Map positions are adequate as basic data for such computations if they have been taken from large scale maps (1:50,000 or greater) of geodetic accuracy. It is difficult to say precisely what effect such points would have on the accuracy of the final results for the length and azimuth of the line. However, assuming the terminal points to be charged with a 25 meter error, the corresponding errors are approximately one second in azimuth and a maximum of fifty meters in distance.

The following derivation has been extracted from the ACIC report, rearranged and expanded to better relate to the actual subroutine. Symbols in capital letters are actual labels of variables as they appear in VECTOR for the most part.

PHI1 = ϕ_1 initial latitude

PHI2 = ϕ_2 terminal latitude

LAMDA1 = λ_1 initial longitude

LAMDA2 = λ_2 terminal longitude

DELAMD = $\Delta\lambda = \lambda_2 - \lambda_1$

(Note: The report shows $\lambda_1 - \lambda_2$, but the sign convention there is positive west; VECTOR uses positive east.)

SINDL = $\sin(\Delta\lambda)$

SIN2DL = $\sin^2(\Delta\lambda)$

COSDL = $\cos(\Delta\lambda)$

TANB1 = $\tan(\beta_1) = (b/a)\bullet\tan(\phi_1)$

TANB2 = $\tan(\beta_2) = (b/a)\bullet\tan(\phi_2)$

where a is the semi-major ellipsoid axis
b is the semi-minor ellipsoid axis
and $f = (a-b)/a$ is defined as the flattening

(Note that many ellipsoids are defined in terms of a and 1/f.)

Then $b/a = (a-a+b)/a = a/a - (a-b)/a = 1 - f$.

$Q = \tan(\phi_1)/\tan(\phi_2)$

QINV = $1/Q = \tan(\phi_2)/\tan(\phi_1)$

$P = (b^2/a^2)\bullet\tan(\phi_1)\bullet\tan(\phi_2)$

$= \{(b/a)\bullet\tan(\phi_1)\}\bullet\{(b/a)\bullet\tan(\phi_2)\}$

$= \tan(\beta_1)\bullet\tan(\beta_2)$

$D_1 = Q - \cos(\Delta\lambda)$

$D_2 = \text{QINV} - \cos(\Delta\lambda)$

$S = Q\bullet\{D_2{}^2 + \sin^2(\Delta\lambda)\} = (1/Q)\bullet\{D_1{}^2 + \sin^2(\Delta\lambda)\}$

$= (1/Q)\bullet[\{Q - \cos(\Delta\lambda)\}^2 + \sin^2(\Delta\lambda)]$

$= (1/Q)\bullet\{Q^2 - 2\bullet Q\bullet\cos(\Delta\lambda) + \cos^2(\Delta\lambda) + \sin^2(\Delta\lambda)\}$

$= (1/Q)\bullet(Q^2 - 2\bullet Q\bullet\cos(\Delta\lambda) + 1)$

$= Q - \cos(\Delta\lambda) + 1/Q - \cos(\Delta\lambda)$

$= D_1 + D_2$

$PS = P\bullet S$

[Hold in floating point register F6 the value

$$J' = (2 \bullet D_1 \bullet D_2)/\{P+\cos(\Delta\lambda)\}$$]

$$\cot(\Delta\sigma) = \{P+\cos(\Delta\lambda)\}/\{\sqrt{PS+\sin^2(\Delta\lambda)}\}$$

$$COT2SG = \cot^2(\Delta\sigma) = \{P+\cos(\Delta\lambda)\}^2/\{PS+\sin^2(\Delta\lambda)\}$$

[then $H' = 1.5 \bullet (Q-1/Q)^2/\{1+\cot^2(\Delta\sigma)\}$]

given $1/n = (2 + 1/n_0) \bullet \{PS+\sin^2(\Delta\lambda)\}/PS - 2$

$$n_0 = (a-b)/(a+b)$$

$$\begin{aligned}
1/n_0 &= (a+b)/(a-b) \\
&= (a+b + a-b)/(a-b) - 1 \\
&= 2 \bullet a/(a-b) - 1 \\
&= 2/f - 1 = ELLIP
\end{aligned}$$

$$\begin{aligned}
1/n &= (2+ELLIP) \bullet \{PS+\sin^2(\Delta\lambda)\}/PS - 2 \\
&= [(2+ELLIP) \bullet \{PS+\sin^2(\Delta\lambda)\}]/PS - 2 \bullet PS/PS \\
&= [(2+ELLIP) \bullet \{PS+\sin^2(\Delta\lambda)\} - 2 \bullet PS]/PS
\end{aligned}$$

$$\begin{aligned}
n &= PS/[2 \bullet \{PS+\sin^2(\Delta\lambda)\} + ELLIP \bullet \{PS+\sin^2(\Delta\lambda)\} - 2 \bullet PS] \\
&= PS/[ELLIP \bullet \{PS+\sin^2(\Delta\lambda)\} + 2 \bullet \sin^2(\Delta\lambda)]
\end{aligned}$$

$$\begin{aligned}
I &= 1 - n + (5/4) \bullet n^2 \\
&= \{(5/4) \bullet n - 1\} \bullet n + 1
\end{aligned}$$

$$\begin{aligned}
COTDW = \cot(\Delta\omega) &= \cot(\Delta\sigma) \bullet \{I - 2 \bullet J - (3/2) \bullet H\} \\
&= \cot(\Delta\sigma) \bullet [I - (n/S) \bullet (2 \bullet D_1 \bullet D_2)/\{P+\cos(\Delta\lambda)\} \\
&\quad - (n/S)^2 \bullet \{1.5 \bullet (Q-1/Q)^2\}/\{1+\cot^2(\Delta\sigma)\}] \\
&= \cot(\Delta\sigma) \bullet \{I - (n/S) \bullet J' - (n/S)^2 \bullet H'\} \\
&= \sqrt{\cot^2(\Delta\sigma)} \bullet [I - (n/S) \bullet \{J' + (n/S) \bullet H'\}]
\end{aligned}$$

$$\Delta\omega = \cot^{-1}(COTDW)$$

DSTNCE(in meters) $= I \bullet a \bullet \Delta\omega$

In all of the calculations, $\Delta\lambda$ is to be the polar angle < π (180°). But since $\cos(2\pi - \alpha) = +\cos(\alpha)$ and distance calculations used only $\sin^2(\Delta\lambda)$, where $\sin(2\pi - \alpha) = -\sin(\alpha)$, the direction of $\Delta\lambda$ has made no difference so far. However, azimuth calculations need the proper sign on $\sin(\Delta\lambda)$. Note first that if $\Delta\lambda$ is zero, the heading is to be determined by comparing the magnitude of initial and terminal latitudes. If $\phi_2 \geq \phi_1$, azm = 0°, else azm = 180.0°. If $\Delta\lambda$ is not zero, but $\sin(\Delta\lambda)$ is zero, i.e., $\Delta\lambda = \pi$, azm = 0.0°.

It turns out that no adjustment need be made to the sign of $\sin(\Delta\lambda)$. First consider the line on the surface of the earth that is being measured. Since $\Delta\lambda = \lambda_2 - \lambda_1$ and a positive east convention has been assumed, $\Delta\lambda > \pi$ only when the line being measured crosses the international date line. Here $\Delta\lambda > \pi$ would indicate using the identity $\sin(2\pi - \alpha) = -\sin(\alpha)$, since the polar angle of interest is $2\pi - \Delta\lambda$. However, due to crossing the date line, the sign of this angle is wrong according to a positive east convention. Thus the desired angle is actually $-(2\pi - \Delta\lambda)$ or $\Delta\lambda - 2\pi$, but the -2π may be dropped. Therefore, we end up with $\sin(\Delta\lambda)$ again and no further adjustments need be made to calculate the azimuth as:

$$\cot(E_{12}) = \frac{\cos(\beta_1)\bullet\{\tan(\beta_2)-\tan(\beta_1)\bullet\cos(\Delta\lambda)\}\bullet\sqrt{1-e^2\cos^2(\beta_1)}}{\sin(\Delta\lambda)}$$

where E_{12} is the elliptic arc forward azimuth (heading)

and e^2 is the major eccentricity squared

$$ESQD = e^2 = (a^2 - b^2)/a^2$$

$$\cos(\beta_1) = \sqrt{\cos^2(\beta_1)}$$

$$\cos^2(\beta_1) = 1/\sec^2(\beta_1) = 1/\{1+\tan^2(\beta_1)\}$$

$$1 - e^2\cos^2(\beta_1) = 1 - e^2/\{1+\tan^2(\beta_1)\}$$

$$= \{1+\tan^2(\beta_1)-e^2\}/\{1+\tan^2(\beta_1)\}$$

$$\cos(\beta_1)\bullet\sqrt{1-e^2\cos^2(\beta_1)} = \sqrt{\{\sec^2(\beta_1)-e^2\}}/\sec^2(\beta_1)$$

$$E_{12} = \cot^{-1}\left(\frac{\{\tan(\beta_2)-\tan(\beta_1)\bullet\cos(\Delta\lambda)\}\bullet\sqrt{\sec^2(\beta_1)-e^2}}{\sin(\Delta\lambda)\bullet\sec^2(\beta_1)}\right)$$

The arccot function returns an angle between $-\pi$ and π. if $E_{12} < 0$, add 2π to give a heading between 0° and 360°.

Use

When the coordinates are expressed in degrees, minutes and seconds, linkage in a calling program is made by:

```
CALL VECTOR (alatd,alatm,alats,alond,alonm,alons,alonew,
             blatd,blatm,blats,blond,blonm,blons,blonew,
             dstnce,[head,]i)
```

where:

alatd, alatm, alats - latitude of the initial point in degrees, minutes, seconds (4-byte arguments)

alond, alonm, alons - longitude of the initial point in degrees, minutes, seconds (4-byte arguments)

alonew - hemisphere of the initial longitude point; 'W' is west. (1-character argument)

blatd, etc. - latitude, longitude and hemisphere of the terminal point

dstnce - the computed distance between point 'a' and point 'b' (single or double precision real/comp-1 or comp-2 (see i below))

head - the forward azimuth measured clockwise from north. If head is omitted or is initialized to a value of 999.0, the azimuth computation is suppressed. (single or double precision real/comp-1 or comp-2 (see i below))

i - the unit of measure that dstnce and head are to be computed in; i is defined as a four byte argument, but is actually interpreted as two halfwords, i' and i" with compatibility to a fullword integer. If the lower (bytes 3 and 4) halfword, i" < 0, then dstnce is returned as a double precision real (comp-2) value, otherwise as a single precision (comp-1) value. The units are based on the absolute value where:

|i"| =	1 returns	nautical miles,
	2	feet,
	3	statute miles,
	4	kilometers,
	else	meters.

If the upper (bytes 1 and 2) halfword, i' < 0, then head is returned as double precision real (comp-2), otherwise as a single precision value. The units returned are specified by the absolute value where:

|i'| = 0 or	1 returns	degrees,
	2	minutes,
	3	seconds,
	else	radians.

If coordinates are expressed as degrees, minutes and seconds and are grouped in a 16 word array of 4-byte arguments arranged as:

array(01)	alatd
(02)	alatm
(03)	alats
(04)	alatns
(05)	alond
(06)	alonm
(07)	alons
(08)	alonew
(09)	blatd
(10)	blatm
(11)	blats
(12)	blatns
(13)	blond
(14)	blonm
(15)	blons
(16)	blonew

then use the calling sequence:

```
CALL VECTOR (array,dstnce,[head,]i)
```

Words 4, 8, 12 and 16 of the array are A4 (Hollerith) or PIC X(4) character data with blank fill.

When the coordinates are expressed in radians or composite arc seconds, the linkage is:

```
CALL VECTOR (alat,alon,alonew,blat,blon,blonew,
             dstnce,[head,]i)
```

where alonew, blonew, dstnce, head and i are as described above and alat, alon, blat and blon are the latitude and longitude of the initial and terminal points in units of:

1) radians if in floating point
2) arc seconds if in binary integer.

A variant of this call is:

```
CALL VECTOR (alat,alon, blat,blon,
             dstnce,[head,]i)
```

where longitude hemisphere indicators are omitted and the latitude and longitude are signed values with north and east as positive.

Known Limitations

Accuracy has been tested only to 6000 statute miles. Due to the ratios of tangents that are calculated, points that are exactly on the equator (0°) and mathematically "close" to the poles (±90°) will cause an abort due to a divide by zero check. However a latitude close to the equator may be specified as approximately in the range of 10^{-10} arc seconds to prevent the divide by zero condition.

Remarks

The arguments listed as "4-byte arguments" may be either single precision real/comp-1 or signed binary full-word integer/comp. There is one exception: if the latitude and longitude are being supplied as arc radians, and the distance is being requested in double precision, then the latitude and longitude are also assumed to be double precision values. The results are always returned as floating point values, either single precision/comp-1 or double precision/comp-2 as requested by the signs of i' and i".

The alias RADVEC may be used in place of VECTOR in any of the calls described.

APPENDIX C

VECTOR SOURCE

```
VECTOR   TITLE '*** SUBROUTINE(S)  VECTOR/RADVEC  ***'
* AUTHOR:  MAJ. S. V. PETERSEN, HQ SAC/ADINSD;  EXT. 3952
* DATE WRITTEN:  1 NOV 76


* REFERENCE:  ACIC TECHNICAL REPORT NUMBER 80,
*            "GEODETIC DISTANCES AND AZIMUTH COMPUTATIONS
*                      FOR LINES OVER 500 MILES"


* DISTANCES ARE CALCULATED AS A GREAT ELLIPTIC, USING THE
* SCHREITER-THOMAS METHOD AS DESCRIBED IN APPENDIX I OF THE
* REPORT.  SOME OF THE COMPUTATIONS HAVE BEEN MANIPULATED
* INTO A DIFFERENT FORM TO FACILITATE PROCESSING.
* SOME ERRORS ALSO APPEAR IN THE WRITE-UP, WHICH HOPEFULLY
* HAVE BEEN CORRECTED.

* IF THIS ROUTINE IS ASSEMBLED WITH AN ASSEMBLER THAT ALLOWS
* THE "SYSPARM" OPTION, THE SPHEROID USED FOR A BASE OF
* CALCULATION MAY BE CHANGED AT ASSEMBLY TIME.  ENTER THE
* NAME OF THE DESIRED SPHEROID AS THE SYSPARM VALUE AS:
*            SYSPARM(AIRY)
*            SYSPARM(A.M.S.)
*            SYSPARM(BESSEL)
*            SYSPARM(CLARK 1866)
*            SYSPARM(CLARK 1880)
*            SYSPARM(INTERNATIONAL)
*            SYSPARM(HAYFORD)        SAME AS INTERNATIONAL
*            SYSPARM(KRASSOVSKY)
* THE DEFAULT SPHEROID IS THE CLARK 1866 DATUM.
```

```
         GBLB  &IBM360              SET TO 1 FOR USE ON 360
&IBM360  SETB  0
         GBLB  &AIRY,&AMS,&BESSEL,&CLK1866,&CLK1880,&HAYFORD
         GBLB  &KRSVSKY
         AIF   (&IBM360).IREC3A     NO &SYSPARM ON 360
.IREC0   AIF   ('&SYSPARM' NE 'AIRY').IREC1
&AIRY    SETB  1
         AGO   .IREC99
.IREC1   AIF   ('&SYSPARM' NE 'A.M.S.').IREC2
&AMS     SETB  1
         AGO   .IREC99
.IREC2   AIF   ('&SYSPARM' NE 'BESSEL').IREC3
&BESSEL  SETB  1
         AGO   .IREC99
.IREC3   AIF   ('&SYSPARM' NE 'CLARK 1866').IREC4
.IREC3A  ANOP   CLARK1866 IS THE DEFAULT DATUM
&CLK1866 SETB  1
         AGO   .IREC99
.IREC4   AIF   ('&SYSPARM' NE 'CLARK 1880').IREC5
&CLK1880 SETB  1
         AGO   .IREC99
.IREC5   AIF   ('&SYSPARM' EQ 'INTERNATIONAL').IREC5A
         AIF   ('&SYSPARM' NE 'HAYFORD').IREC6
.IREC5A  ANOP
&HAYFORD SETB  1
         AGO   .IREC99
.IREC6   AIF   ('&SYSPARM' NE 'KRASSOVSKY').IREC3A
&KRSVSKY SETB  1
.IREC99  ANOP
         PUNCH '       ALIAS    RADVEC'
```

```
VECTOR   CSECT
         USING *,R15
         B     PASTCONS
         DC    AL1(L'VCTID)
VCTID    DC    C'VECTOR/RADVEC'
         AIF   (&IBM360).SKDT
         DC    C'.&SYSDATE..&SYSTIME'

.SKDT    ANOP
RADVEC   EQU   VECTOR
         ENTRY RADVEC

SAVEAREA DC    9D'0'

UNIT     DC    D'1852.'                  METERS/NAUTICAL MILE
         DC    D'0.3048'                 METERS/FOOT
         DC    D'1609.344'               METERS/STATUTE MILE
         DC    D'1000.'                  METERS/KILOMETER
NUNITS   EQU   (*-UNIT)/8

PI       DC    D'3.141592653589793238462643'
TWOPI    DC    D'6.283185307179586476925286'
RADDEG   DC    D'57.29577951308232087679816'  DEGREES/RADIAN
         DC    D'3437.746770784939252607890'  MINUTES/RADIAN
         DC    D'206264.8062470963551564734'  SECONDS/RADIAN
NAUNS    EQU   (*-RADDEG)/8

UNZR1    DC    XL8'4E00000000000000'
DL4OVPI  DC    XL8'41145F306DC9C883'     4/PI

F0       EQU   0
F2       EQU   2
F4       EQU   4
F6       EQU   6
R0       EQU   0
R1       EQU   1
R2       EQU   2
R3       EQU   3
R4       EQU   4
R5       EQU   5
R6       EQU   6
R7       EQU   7
R8       EQU   8
R9       EQU   9
R10      EQU   10
R11      EQU   11
R12      EQU   12
R13      EQU   13
R14      EQU   14
R15      EQU   15
```

```
CONST    DC   D'4.848136811095359936E-6'
         DC   D'60.0'
         DC   D'60.0'


ACTC1    DC   XL8'BF1E31FF1784B965'
ACTC2    DC   XL8'C0ACDB34C0D1B35D'
ACTC3    DC   XL8'412B7CE45AF5C165'
ACTC4    DC   XL8'C11A8F923B178C78'
ACTC5    DC   XL8'412AB4FD5D433FF6'
ACTC6    DC   XL8'C02298BB68CFD869'
ACTC7    DC   XL8'41154CEE8B70CA99'
ONE      DC   D'1.0'
ACTC9    DC   XL8'411BB67AE8584CAB'      SQRT(3)
ACTD1    DC   D'0.0'
         DC   XL8'C0860A91C16B9B2C'     -.52359884
PIOV2    DC   XL8'411921FB54442D18'      PI/2
         DC   XL8'4110C152382D7365'
ACTCE    DC   XL4'0E000000'
ACTCF2   DC   XL4'F2000000'
ACTC3A   DC   XL4'3A100000'
ACTC40   DC   XL4'40449851'

SCA      DC   XL8'3778FCE0E5AD1685'                 SIN
         DC   XL8'B66C992E84B6AA37'                      COS
SCB      DC   XL8'B978C01C6BEF8CB3'                 SIN
         DC   XL8'387E731045017594'                      COS
SCC      DC   XL8'3B541E0BF684B527'                 SIN
         DC   XL8'BA69B47B1E41AEF6'                      COS
SCD      DC   XL8'BD265A599C5CB632'                 SIN
         DC   XL8'3C3C3EA0D06ABC29'                      COS
SCE      DC   XL8'3EA335E33BAC3FBD'                 SIN
         DC   XL8'BE155D3C7E3C90F8'                      COS
SCF      DC   XL8'C014ABBCE625BE41'                 SIN
         DC   XL8'3F40F07C206D6AB1'                      COS
SCG      DC   XL8'40C90FDAA22168C2'      PI/4       SIN
         DC   XL8'C04EF4F326F91777'                      COS
PIOV4    EQU  SCG
ZERO     EQU  ACTD1

TCTA     DC   XL8'C41926DBBB1F469B'
TCTB     DC   XL8'4532644B1E45A133'
TCTC     DC   XL8'C5B0F82C871A3B68'
TCTD     DC   XL8'C58AFDD0A41992D4'
TCTE     DC   XL8'44AFFA6393159226'
TCTF     DC   XL8'C325FD4A87357CAF'
TCTG     DC   XL8'422376F171F72282'
```

```
*        REFERENCE ELLIPSOID CONSTANTS
*
*        A = SEMI-MAJOR AXIS (METERS)
*        F = FLATTENING = (A-B)/A
*        FINV = 1/F
*        ESQD      MAJOR-ECCENTRICITY SQUARED
*                  = (A**2 - B**2)/A**2
*        BOVRA     SEMI-MINOR/SEMI-MAJOR = 1 - F
*        NO = (A-B)/(A+B)
*        ELLIP = 1/NO = 2*FINV - 1
*
*        A         1/F          B             F
*                                             E**2
.REC1    AIF   (NOT &CLK1866).REC2
.RECDF   ANOP
*  CLARK 1866
*  6378206.4000 294.978698 6356583.8000 .00339007530393
*                                       .00676865799729

A        DC    D'6378206.40'
ESQD     DC    D'.00676865799729'
BOVRA    DC    D'0.99660992469607'
ELLIP    DC    D'588.957396'
         AGO   .REC99
.REC2    AIF   (NOT &HAYFORD).REC3
*  INTERNATIONAL (HAYFORD)
*  6378388.0000 297.000000 6356911.9461 .00336700336700
*                                       .00672267002233

A        DC    D'6378388.00'
ESQD     DC    D'0.00672267002233'
BOVRA    DC    D'0.9966329966329966632'
ELLIP    DC    D'593.0'
         AGO   .REC99
.REC3    AIF   (NOT &KRSVSKY).REC4
*  KRASSOVSKY
*  6378245.0000 298.300000 6356863.0188 .00335232986926
*                                       .00669342162297

A        DC    D'6378245.0'
ESQD     DC    D'0.00669342162297'
BOVRA    DC    D'0.99664767013074'
ELLIP    DC    D'595.6'
         AGO   .REC99
```

```
.REC4    AIF    (NOT &CLK1880).REC5
*  CLARK 1880
*  6378249.1450 293.465000 6356514.8695 .00340756137870
*                                       .00680351128285

A        DC     D'6378249.1450'
ESQD     DC     D'.00680351128285'
BOVRA    DC     D'0.9965924386213'
ELLIP    DC     D'585.930'
         AGO    .REC99
.REC5    AIF    (NOT &AIRY).REC6
*  AIRY
*  6376542.0000 299.300000 6355237.1487 .00334112930170
*                                       .00667109545840

A        DC     D'6376542.00'
ESQD     DC     D'.00667109545840'
BOVRA    DC     D'0.9966588706983'
ELLIP    DC     D'597.60'
         AGO    .REC99
.REC6    AIF    (NOT &AMS).REC7
*  A.M.S.
*  6378270.0000 297.000000 6356794.3434 .00336700336700
*                                       .00672267002233

A        DC     D'6378270.00'
ESQD     DC     D'0.00672267002233'
BOVRA    DC     D'0.996632996632996632'
ELLIP    DC     D'593.0'
         AGO    .REC99
.REC7    AIF    (NOT &BESSEL).RECDF
*  BESSEL
*  6377397.1550 299.152813 6356078.9628 .00334277318503
*                                       .00667437223749

A        DC     D'6377397.1550'
ESQD     DC     D'.00667437223749'
BOVRA    DC     D'0.99665722681497'
ELLIP    DC     D'597.305625'


.REC99   ANOP
```

```
WKAREA   DC    D'0'

COORDS   DS    0D
LAMDA2   DC    D'0'                   LONGITUDE TERMINAL POINT
PHI2     DC    D'0'                   LATITUDE  TERMINAL POINT
LAMDA1   DC    D'0'                   LONGITUDE INITIAL  POINT
PHI1     DC    D'0'                   LATITUDE  INITIAL  POINT


SINDL    DC    D'0'                   SIN(DELAMD)
SIN2DL   DC    D'0'                   SIN**2(DELAMD)
COSDL    DC    D'0'                   COS(DELAMD)
TANB1    DC    D'0'                TAN(BETA1) = (B/A)*TAN(PHI1)
TANB2    DC    D'0'                   TAN(BETA2)
S        DC    D'0'                   D1 + D2
PS       DC    D'0'                   P*S
DELAMD   EQU   LAMDA1                 LAMDA2 - LAMDA1
COT2SG   EQU   LAMDA2                 COT**2(DELTA_SIGMA)
TB2      EQU   COT2SG                 TEMP STORE
COTDW    EQU   COT2SG                 COT(DELTA_OMEGA)
TANPH1   EQU   LAMDA2                 TAN(PHI1)
D1       EQU   LAMDA2                 Q - COSDL
SWITCH   EQU   S
I        EQU   PS                     1 - N + 1.25*N**2
IJH      EQU   S                      I - 2*J - 1.5*H


TEMP2    DC    D'0'
PCOSDL   DC    F'0'              P+COS(DELAMD)  (NEED THE SIGN)
SCQ      EQU   PCOSDL+3


MINM     DC    XL4'35400000'
C24M8    DC    F'24,-8'
```

```
PASTCONS STM    R14,R12,12(R13)
         LR     R2,R13
         LA     R13,SAVEAREA
         DROP   R15
         USING  SAVEAREA,R13
         ST     R2,4(R13)
         ST     R13,8(R2)
         MVI    SWITCH,0
         LM     R4,R5,C24M8
         LA     R6,STORAD
         LR     R2,R1                 COUNT THE NUMBER OF PARMS
         LA     R14,4                 PASSED
         LA     R15,(17-1)*4-8(R1)
CNTPRMS  TM     8(R2),X'80'           ABSOLUTE MINIMUM IS THREE
         BO     EOFLST
         BXLE   R2,R14,CNTPRMS
         B      WRNGNBR

EOFLST   LM     R10,R12,0(R2)         A(DSTNCE,HEAD(?),IUNIT)
         SR     R2,R1
         SRL    R2,2
         IC     R14,BTBL(R2)
         B      WRNGNBR(R14)



*           #ARGS = 3,     4,  5,    6,      7,      8,      9,
BTBL     DC AL1(NOHEAD@,ARG4@,0,NOHEAD@,ARG7@,NOHEAD@,ARG9@)
         DC AL1(0,0,0,0,0,0,NOHEAD@,ARG17@,0)
*             10 ----- 15,    16,      17
WRNGNBR  DC     X'B2E0',H'32' THIS INVALID OPCODE TERMINATES
         DC     CL32'WRONG NUMBER OF ARGUMENTS PASSED'
         B      RTN

NOHEAD   LR     R10,R11     OPTIONAL AZIMUTH PARAMETER MISSING
NOHEAD@  EQU    NOHEAD-WRNGNBR
         LA     R11,=E'999.0'         SUPPRESS THE CALCULATION
         IC     R14,BTBL+1(R2)
         B      WRNGNBR(R14)
```

```
*        VECTOR (ALATD,ALATM,ALATS, ALNGD,ALNGM,ALNGS,AEW,
*                BLATD,BLATM,BLATS, BLNGD,BLNGM,BLNGS,BEW,
*                DSTNCE, <HEAD,> IUNIT)

ARG17    LA    R14,DMSRAD
ARG17@   EQU   ARG17-WRNGNBR
DMSRAD   LD    F0,ZERO
         LA    R3,16                  INDEX
CNVRT17  L     R15,0(R1)
         LA    R1,4(R1)
         MVC   WKAREA(4),0(R15)       MOVE IN VALUE
         TM    WKAREA,X'FF'
         BM    CV17R                  REAL*4
         BZ    CV17POSI               POSITIVE INTEGER*4
         L     R0,WKAREA              NEGATIVE INTEGER*4
         LPR   R0,R0
         ST    R0,WKAREA
         MVI   WKAREA,X'80'           MAKE NEGATIVE
CV17POSI OI    WKAREA,X'46'       INTEGER.  MAKE AN UNNORM REAL
CV17R    AD    F0,WKAREA
         MD    F0,CONST(R3)
         BXH   R3,R5,CNVRT17
         BR    R6                 TO CHECK EAST/WEST AND STORE.
```

```
*         VECTOR  (LATR1, LNGR1, <AEW,>  LATR2, LNGR2, <BEW,>
*                   DSTNCE, <HEAD,> IUNIT)


ARG7      LA     R6,STVL
ARG7@     EQU    ARG7-WRNGNBR


ARG9      LA     R14,RADSEC
ARG9@     EQU    ARG9-WRNGNBR
RADSEC    L      R15,0(R1)
          LA     R1,4(R1)
          TM     0(R15),X'FF'
          BNM    ARGSEC
          SDR    F0,F0           LOAD A SINGLE PRECISION RADIAN
          LE     F0,0(R15)      INPUT VALUE UNLESS THE DISTANCE
          TM     2(R12),X'80' IS REQUESTED IN DOUBLE PRECISION
          BNOR   R6
          LD     F0,0(R15)              REAL*8  RADIANS
          BR     R6


ARGSEC    L      R0,0(R15)
          LPR    R0,R0
          ST     R0,WKAREA              INTEGER SECONDS
          MVI    WKAREA,X'46'
          TM     0(R15),X'80'
          BNO    *+8
          XI     WKAREA,X'80'           MAKE NEGATIVE
          LD     F0,WKAREA
          MD     F0,CONST               CONVERT TO RADIANS
          BR     R6


STORAD    XI     SWITCH,1
          BNZ    STVL                   BRANCH ON LATITUDE
          L      R15,0(R1)
          LA     R1,4(R1)
          CLI    0(R15),C'W'
          BNE    STVL
          LCDR   F0,F0                  COMPLEMENT ON WEST
STVL      STD    F0,COORDS(R4)
          BXH    R4,R5,0(R14)
          B      DONECVRT                (F0)  = COORDS(0)  = LAMDA2
```

```
*         VECTOR (LTLNARR, DSTNCE, <HEAD,> IUNIT)

ARG4      L      R15,0(R1)            ARRAY OF 16 WORDS;  SAME
ARG4@     EQU    ARG4-WRNGNBR         ORDER AS
          LA     R1,4(R1)             ARG17 PARMS, BUT ADD A
*                                     WORD FOR LAT NORTH/SOUTH
ARRDMS    LD     F0,ZERO
          LA     R3,16
CNVRT4    MVC    WKAREA(4),0(R15)
          LA     R15,4(R15)
          TM     WKAREA,X'FF'
          BM     CV4R                 REAL*4
          BZ     CV4POSI              POSITIVE INTEGER*4
          L      R0,WKAREA            NEGATIVE INTEGER*4
          LPR    R0,R0
          ST     R0,WKAREA
          MVI    WKAREA,X'80'         MAKE NEGATIVE
CV4POSI   OI     WKAREA,X'46'     INTEGER.  MAKE AN UNNORM REAL
CV4R      AD     F0,WKAREA
          MD     F0,CONST(R3)
          BXH    R3,R5,CNVRT4
          CLI    0(R15),C'S'
          BE     WORS
          CLI    0(R15),C'W'
          BNE    *+6                  IGNORE E, N
WORS      LCDR   F0,F0                COMPLEMENT WEST, SOUTH
          STD    F0,COORDS(R4)
          LA     R15,4(R15)
          BXH    R4,R5,ARRDMS
*         B      DONCVRT              (F0) = COORDS(0) = LAMDA2
```

```
DONECVRT DS     0H
*        LD     F0,LAMDA2
         SD     F0,LAMDA1
         STD    F0,DELAMD              POLAR ANGLE
         BNZ    KALLSIN
         STD    F0,SINDL               SIN(0) = 0
         STD    F0,SIN2DL
         LD     F6,PHI1           IS THIS A ZERO DISTANCE CALL?
         CD     F6,PHI2
         BE     STDST                   YES
         LD     F0,ONE                        COS(0) = 1.
         B      STCOSDL


KALLSIN  LA     R15,4                  SINE OF NEGATIVE VALUE
         BM     *+6
         SR     R15,R15                SINE OF POSITIVE VALUE
         BAL    R7,SC1
         STD    F0,SINDL
         MDR    F0,F0
         STD    F0,SIN2DL
         LD     F0,DELAMD
         LA     R15,2                  COSINE OF VALUE
         BAL    R7,SC1
STCOSDL  STD    F0,COSDL
         LD     F0,PHI1
         BAL    R7,TANG
         TM     PHI1,X'80'
         BNO    *+6
         LCDR   F0,F0
         STD    F0,TANPH1
         MD     F0,BOVRA
         STD    F0,TANB1               PARAMETRIC LATITUDE
         LD     F0,PHI2
         BAL    R7,TANG
         TM     PHI2,X'80'
         BNO    *+6
         LCDR   F0,F0
         LDR    F6,F0
         LD     F4,TANPH1
         DDR    F6,F4                  QINV = 1/Q
         DDR    F4,F0                  Q = TAN(PHI1)/TAN(PHI2)
         MD     F0,BOVRA
         STD    F0,TANB2
         MD     F0,TANB1               (F0) = P
         LDR    F2,F4
         SDR    F2,F6                  (F2) = Q - 1/Q
         SD     F4,COSDL               (F4) = D1
         STD    F4,D1
         SD     F6,COSDL               (F6) = D2
         ADR    F4,F6
         BZ     SZERO
```

```
         STD    F4,S                S = D1 + D2
         MDR    F4,F0
         STD    F4,PS               P*S
         LTDR   F4,F4
         BNP    SZERO
         AD     F4,SIN2DL           PS + SIN**2(DELAMD)
         AD     F0,COSDL             P + COS(DELAMD)
         STE    F0,PCOSDL
         DDR    F6,F0                    D2/(P+COS(DELAMD))
         MD     F6,D1                 D1*
         ADR    F6,F6               2*
         MDR    F0,F0               (P+COS(DELAMD))**2
         DDR    F0,F4                   /(PS+SIN**2(DELAMD))
         STD    F0,COT2SG                 = COT**2(DELSIGMA)
         AD     F0,ONE
         MDR    F2,F2                   (Q-1/Q)**2
         DDR    F2,F0                             /(COT2SG+1)
         MD     F2,=D'1.5'          1.5*                   "H"
         MD     F4,ELLIP
         AD     F4,SIN2DL
         AD     F4,SIN2DL
         LD     F0,PS
         DDR    F0,F4               (F0) = N
         LD     F4,=D'1.25'         (1.25
         MDR    F4,F0                    *N
         SD     F4,ONE                     -1)
         MDR    F4,F0                         *N
         AD     F4,ONE                          +1
         STD    F4,I                               = I
         DD     F0,S                (F0) = N/S
         MDR    F2,F0
         ADR    F2,F6
         MDR    F2,F0
         SDR    F4,F2
         LD     F2,COT2SG
         BAL    R7,SQT
         MDR    F0,F4
         LD     F2,ONE
         BAL    R7,ACT
         TM     PCOSDL,X'80'
         BNO    CALCL
         SD     F0,PI
         LPER   F0,F0
CALCL    MD     F0,I
CALCLE   MD     F0,A                (F0) = DISTANCE IN METERS
         LH     R15,2(R12)          CHECK DISTANCE UNITS
         LPR    R15,R15
         BZ     STDST
         C      R15,=A(NUNITS)
         BH     STDST
         SLA    R15,3
         DD     F0,UNIT-8(R15)
```

```
STDST    TM     2(R12),X'80'
         BNO    STDSTE
         STD    F0,0(R10)      RETURN AS "DSTNCE" VALUE  REAL*8
         B      CHKAZM

STDSTE   DS     0H
         AIF    (&IBM360).V1
         LRER   F0,F0             ON A 370, WE CAN ROUND NICELY
.V1      STE    F0,0(R10)      RETURN AS "DSTNCE" VALUE  REAL*4


CHKAZM   CLC    0(4,R11),=E'999.0'  AZIMUTH DESIRED?
         BE     RTN

         LD     F4,SINDL
         LPDR   F0,F4
         BNZ    CALCHEAD
         LD     F6,PHI1             SIN(DELAMD) = 0
         TM     COSDL,X'80'
         BNO    CH0
         LCER   F6,F6                (POLAR ANGLE IS PI)
CH0      CD     F6,PHI2           IF COS(DELAMD)*PHI1 < PHI2
         BNH    STHD                           HEAD = 0.0;
LDPI     LD     F0,PI                     ELSE HEAD = 180
         B      STHDPI

CALCHEAD LD     F2,TANB1
         MDR    F2,F2
         AD     F2,ONE
         MDR    F4,F2               SINDL*SEC2B1
         STD    F4,SINDL
         SD     F2,ESQD
         STD    F2,TB2
         BAL    R7,SQT
         LD     F4,TANB2
         LD     F6,TANB1
         MD     F6,COSDL
         SDR    F4,F6
         MDR    F0,F4
         STD    F0,TB2
         LD     F2,SINDL
         LPER   F2,F2
         LPER   F0,F0
         BZ     CH1
         STE    F2,TEMP2
         L      R14,TEMP2
         STE    F0,TEMP2
         S      R14,TEMP2
         C      R14,ACTCE
         BNH    CH2
CH1      LD     F0,PIOV2
         B      CHSGN
```

```
CH2      TM    TB2,X'80'
         BNO   CHACT
         C     R14,ACTCF2
         BL    LDPI
CHACT    BAL   R7,ACT
CHSGN    TM    TB2,X'80'
         BNO   *+10
         LCDR  F0,F0
         AD    F0,PI
         TM    SINDL,X'80'
         BNO   *+10
         LCDR  F0,F0
         AD    F0,TWOPI
STHDPI   LH    R15,0(R12)          CHECK AZIMUTH UNITS
         LPR   R15,R15
         BZ    STCNV               GIVE DEGREES ON 0 OR 1
*      COULD BE A 1 IF A NEGATIVE FULL WORD WAS GIVEN AS FLAG
         BCTR  R15,0
         C     R15,=A(NAUNS)
         BNL   STHD                RADIANS ON ALL ELSE
         SLL   R15,3
STCNV    MD    F0,RADDEG(R15)
STHD     TM    0(R12),X'80'
         BNO   STHDE
         STD   F0,0(R11)
         B     RTN


STHDE    DS    0H
         AIF   (&IBM360).V2
         LRER  F0,F0               ROUND ON A 370
.V2      STE   F0,0(R11)


RTN      L     R13,4(R13)
         RETURN (14,12),T,RC=0

SZERO    LD    F0,ZERO
         TM    COSDL,X'80'
         BZ    STDST
         LD    F0,=D'3.1362'       ELLIPTIC CIRCUMFERENCE
         B     CALCLE
```

```
SQT      LPDR  F0,F2                    SQUARE ROOT FUNCTION
         BZR   R7                       RETURN ON ZERO
         SR    R14,R14
         IC    R14,TB2
         LA    R14,X'31'(R14)
         SRDL  R14,1
         STC   R14,TB2
         LE    F6,TB2
         MVC   TB2+1(3),=X'423A2A'
         AE    F6,TB2
         ME    F6,=X'48385F07'
         LTR   R15,R15
         BNM   SQT1
         AER   F6,F6
         AER   F6,F6
SQT1     DER   F2,F6
         AUR   F6,F2
         HER   F6,F6                  REFINE USING HERON'S METHOD
         LER   F2,F0                    (NEWTON-RAPHSON)
         DER   F2,F6
         AUR   F6,F2
         HER   F6,F6
         LDR   F2,F0
         DDR   F2,F6
         AWR   F6,F2
         HDR   F6,F6
         DDR   F0,F6
         SDR   F0,F6
         HER   F0,F0
         SU    F0,TB2
         AU    F0,TB2
         ADR   F0,F6
         BR    R7


         LTORG
```

```
SC1      BAL   R14,OCTANT          SINE/COSINE
         LA    R15,8               CALC COSINE?
         TM    SCQ,X'03'
         BM    SC5                  YES
         SR    R15,R15              NO, CALC SIN
SC5      CE    F4,MINM
         BH    SC6
         LD    F0,ZERO
         B     SC7+2(R15)
SC6      MDR   F0,F0
         LDR   F2,F0
         MD    F0,SCA(R15)
         AD    F0,SCB(R15)
         MDR   F0,F2
         AD    F0,SCC(R15)
         MDR   F0,F2
         AD    F0,SCD(R15)
         MDR   F0,F2
         AD    F0,SCE(R15)
         MDR   F0,F2
         AD    F0,SCF(R15)
         MDR   F0,F2
         AD    F0,SCG(R15)
         B     SC7(R15)
SC7      MDR   F0,F4               FOR SIN
         B     SC8
         NOPR  0                      SPACE TO 8 BYTES
         MDR   F0,F2
         AD    F0,ONE
SC8      TM    SCQ,X'04'           IS SCQ 4 TO 7?
         BZR   R7
         LCDR  F0,F0
         BR    R7


OCTANT   LPDR  F0,F0
         MD    F0,DL4OVPI
         CE    F0,ONE
         BL    OCT1
         LDR   F4,F0
         AW    F4,UNZR1
         STD   F4,TEMP2
         AD    F4,UNZR1
         SDR   F0,F4
         AL    R15,TEMP2+4
OCT1     STC   R15,SCQ
         TM    SCQ,X'01'
         BZ    OCT2
         SD    F0,ONE
OCT2     LPDR  F4,F0
         BR    R14
```

```
TANG     SR    R15,R15             TANGENT FUNCTION
         BAL   R14,OCTANT
         LD    F2,TCTG
         LD    F6,ONE
         CE    F4,MINM
         BL    TCT2
         MDR   F0,F0
         LDR   F6,F0
         AD    F6,TCTF
         MDR   F6,F0
         AD    F6,TCTE
         MDR   F2,F0
         AD    F2,TCTA
         MDR   F2,F0
         AD    F2,TCTB
TCT2     MDR   F2,F0
         AD    F2,TCTC
         MDR   F0,F6
         AD    F0,TCTD
         MDR   F0,F4
         TM    SCQ,X'03'
         BM    TCT3
         DDR   F0,F2
         B     TCT4
TCT3     DDR   F2,F0
         LDR   F0,F2

TCT4     TM    SCQ,X'02'
         BZR   R7
         LCDR  F0,F0
         BR     R7
```

```
ACT      CDR   F0,F2              ARCCOTANGENT FUNCTION
         BH    ACT02
         BL    ACT01
         LD    F0,PIOV4       (X) = 1,  LOAD PI/4 AND RETURN
         BR    R7

ACT01    DDR   F0,F2
         LA    R1,16
         B     ACT03
ACT02    DDR   F2,F0
         LDR   F0,F2
         SR    R1,R1
ACT03    LA    R14,ACTD1
         LD    F4,ONE
         CE    F0,ACTC3A
         BNH   ACT05
         CE    F0,ACTC40
         BNH   ACT04
         LDR   F2,F0
         MD    F0,ACTC9
         SDR   F0,F4
         AD    F2,ACTC9
         DDR   F0,F2
         LA    R14,8(R14)
ACT04    LDR   F6,F0
         MDR   F0,F0
         LD    F4,ACTC7
         ADR   F4,F0
         LD    F2,ACTC6
         DDR   F2,F4
         AD    F2,ACTC5
         ADR   F2,F0
         LD    F4,ACTC4
ACT05    DDR   F4,F2
         AD    F4,ACTC3
         ADR   F4,F0
         LD    F2,ACTC2
         DDR   F2,F4
         AD    F2,ACTC1
         MDR   F0,F2
         MDR   F0,F6
         ADR   F0,F6
         SD    F0,0(R1,R14)
         LPER  F0,F0
         BR    R7

         END
```

APPENDIX D

COPY BOOKS FOR COBOL PROGRAMS USING CARTAM

CARTCB07 - COMMUNICATION BLOCK.

```
     05  DDNAME                    PIC X(8)  VALUE 'GEOINDEX'.
     05  FUNCTION-CODE                       VALUE 'OPEN'.
         10  FUNCTION-CODE-1       PIC X.
         10  FUNCTION-CODE-2       PIC X.
         10  FUNCTION-CODE-3       PIC X.
         10  FUNCTION-CODE-4       PIC X.
                 88  CONTINUE-WALK              VALUE ' '.
                 88  DISCARD-SUBTREE            VALUE 'T'.
                 88  KEEP-ALL-CHILDREN          VALUE 'L'.
     05  STATUS-CODE               PIC XX.
                 88  GOOD-CARTAM-OPEN           VALUE '  '.
                 88  SUCCESSFUL-CARTAM          VALUE '  '.
                 88  MORE-PATH                  VALUE '  '.
                 88  END-OF-PARENT              VALUE 'GE'.
     05  MODE-INDICATOR            PIC X.
     05  USER-DATA-PAD-CHARACTER PIC X          VALUE ' '.
     05  NORT-INDICATOR REDEFINES USER-DATA-PAD-CHARACTER
                                   PIC X.
                 88  NODE                       VALUE 'N'.
                 88  TERMINAL-ELEMENT           VALUE 'T'.
                 88  TERMINAL-W-SHORT-KEY       VALUE 'X'.
     05  OPEN-INFO-AREA.
         10  NUMBER-OF-COORDINATES
                                 PIC 9(4) COMP SYNC VALUE 2.
         10  MAX-NUMBER-BUFFERS
                                 PIC 9(4) COMP SYNC VALUE 32.
     05  RECORD-RBA REDEFINES OPEN-INFO-AREA
                                 PIC S9(9) COMP SYNC.
     05  MAX-USER-AREA-LENGTH PIC  9(4) COMP SYNC VALUE 0.
     05  TRUE-USER-DATA-LENGTH PIC 9(4) COMP SYNC VALUE 0.
     05  NUMBER-VSAM-READS    PIC  9(4) COMP SYNC VALUE 0.
     05  NUMBER-VSAM-WRITES   PIC  9(4) COMP SYNC VALUE 0.
```

CARTFNCS - CARTAM FUNCTION CODES.

```
 01  CARTAM-FUNCTION-CODES.
     03  CARTAM-OPEN          PIC XXXX VALUE 'OPEN'.
     03  CARTAM-LOAD          PIC XXXX VALUE 'LOAD'.
     03  CARTAM-ISRT          PIC XXXX VALUE 'ISRT'.
     03  CARTAM-CHNG          PIC XXXX VALUE 'CHNG'.
     03  CARTAM-DLET          PIC XXXX VALUE 'DLET'.
     03  CARTAM-CLOSE         PIC XXXX VALUE 'CLSE'.
     03  GR                   PIC XXXX VALUE 'GR  '.
     03  GRL                  PIC XXXX VALUE 'GR L'.
     03  GM                   PIC XXXX VALUE 'GM  '.
     03  GMP                  PIC XXXX VALUE 'GMP '.
     03  GNP                  PIC XXXX VALUE 'GNP '.
     03  GNPT                 PIC XXXX VALUE 'GNPT'.
     03  GNPL                 PIC XXXX VALUE 'GNPL'.
     03  SUB-FUNCTIONS.
         05  88-CONTINUE-WALK      PIC X VALUE ' '.
         05  88-DISCARD-SUBTREE    PIC X VALUE 'T'.
         05  88-KEEP-ALL-CHILDREN  PIC X VALUE 'L'.
         05  FILLER                PIC X VALUE ' '.
     03  GP                   PIC XXXX VALUE 'GP  '.
     03  GPP                  PIC XXXX VALUE 'GPP '.
     03  GT                   PIC XXXX VALUE 'GT  '.
     03  GTP                  PIC XXXX VALUE 'GTP '.
     03  GC                   PIC XXXX VALUE 'GC  '.
     03  GCP                  PIC XXXX VALUE 'GCP '.
     03  GN                   PIC XXXX VALUE 'GN  '.
```

APPENDIX E

INDEX LOAD PROGRAM SOURCE

```
IDENTIFICATION DIVISION.
  PROGRAM-ID. NTBNDLIX.
  DATE-WRITTEN. NOV77.
  DATE-COMPILED.


ENVIRONMENT DIVISION.

 INPUT-OUTPUT SECTION.

  FILE-CONTROL.
    SELECT NTB-FILE  ASSIGN TO NTBVSAM
           ORGANIZATION IS INDEXED
           ACCESS IS SEQUENTIAL
           RECORD KEY IS V-NTB-KEY
           FILE STATUS IS FILE-STATUS.

    SELECT NDL-FILE ASSIGN TO NDLVSAM
           ORGANIZATION IS INDEXED
           ACCESS IS SEQUENTIAL
           RECORD KEY IS V-ZBKEY
           FILE STATUS IS FILE-STATUS.
```

```
DATA DIVISION.

FILE SECTION.

FD  NTB-FILE
    LABEL RECORDS ARE STANDARD
    BLOCK CONTAINS 0 RECORDS
    RECORD CONTAINS 276 TO 4596 CHARACTERS
    DATA RECORD IS VSAM-NTB-RECORD.

    COPY VSAMNTB.

66  V-IBLATLNG      RENAMES V-IBLAT THRU V-IBLNG-DIR.


FD  NDL-FILE
    LABEL RECORDS ARE STANDARD
    BLOCK CONTAINS 0 RECORDS
    RECORD CONTAINS 340 TO 1840  CHARACTERS
    DATA RECORD IS VSAM-ZB-ZO-RECORD.

    COPY JLPVZBZO.

66  V-ZBLATLNG      RENAMES V-ZBLAT THRU V-ZBLNGSGN.
```

```
WORKING-STORAGE SECTION.


77  EOF-SWITCH          PIC 9           VALUE 0.
                88  EOF                 VALUE 1.

77  RETURN-STATUS       PIC X(04)       VALUE SPACES.
                88  SUCCESSFUL          VALUE '0000'.

77  DISPOSITION         PIC X(03)       VALUE 'SHR'.

77  FILE-STATUS         PIC X(02)       VALUE SPACES.

01  COMMUNICATION-BLOCK.
      COPY CARTCB07.


01  USER-DATA-AREA.
    05  KEY-FEEDBACK-AREA.
        10  NDL-KEY.
            15  ISL                 PIC 9(5).
            15  DGZ                 PIC X(3).
            15  REV                 PIC X.
        10  FILLER                  PIC X(15).
    05  FILLER  REDEFINES  KEY-FEEDBACK-AREA.
        10  NTB-KEY.
            15  ISL                 PIC 9(5).
            15  CAT                 PIC 9(5).
            15  WAK                 PIC 9(4).
            15  BEN                 PIC X(6).
            15  ELT                 PIC X.
        10  FILLER                  PIC X(3).
66  NDL-IGZ RENAMES ISL OF NDL-KEY
              THRU DGZ OF NDL-KEY.
```

```
01  COORDINATE-VECTOR.
    05  NDX-LAT                    PIC S9(9)   COMP SYNC.
    05  NDX-LON                    PIC S9(9)   COMP SYNC.
    05  NDX-DELTA                  PIC S9(9)   COMP SYNC.
01  WK-LAT-LNG.
    03 WK-LAT.
        05 WK-LATD                PIC 9(02) VALUE 0.
        05 WK-LATM                PIC 9(02) VALUE 0.
        05 WK-LATS                PIC 9(02) VALUE 0.
        05 WK-LAT-DIR             PIC X(01) VALUE SPACE.
    03 WK-LONG.
        05 WK-LONGD               PIC 9(03) VALUE 0.
        05 WK-LONGM               PIC 9(02) VALUE 0.
        05 WK-LONGS               PIC 9(02) VALUE 0.
        05 WK-LONG-DIR            PIC X(01) VALUE SPACE.


01  ALLOCATED-DSN.
    03  FILLER              PIC X(04) VALUE 'JLP.'.
    03  FILLER              PIC X(08) VALUE 'VSAMNDL.'.
    03  FILLER              PIC X(05) VALUE 'ZBZO.'.
    03  REV-FOR-DSN         PIC X(01) VALUE 'B'.
    03  FILLER              PIC X(01) VALUE SPACE.


01  DD-NAME                 PIC X(08) VALUE 'NDLVSAM '.


01  DUMMY-DD-NAME.
    03  FILLER              PIC X(07) VALUE 'DUMMYDD'.
    03  DUMMY-DD-NAME-REV   PIC X(01) VALUE 'B'.



01  VALUE-OF-REV-TABLE      PIC X(03) VALUE 'BCD'.
01  TABLE-OF-REV-VALUES
          REDEFINES VALUE-OF-REV-TABLE.
    03  REV-LETTER      PIC X    OCCURS 3 TIMES
                        INDEXED BY REV-NDX.


01  ACCUMULATORS.
    03  ONE-CON        PIC S9(06) COMP SYNC VALUE +1.
    03  TOTAL-ISRTS    PIC S9(06) COMP SYNC VALUE +0.
    03  TOTAL-GETS     PIC S9(06) COMP SYNC VALUE +0.
    03  TOTAL-PUTS     PIC S9(06) COMP SYNC VALUE +0.
```

```
PROCEDURE DIVISION.


000-OPEN-INITIALIZE.
    MOVE 24 TO MAX-USER-AREA-LENGTH.
    MOVE 'LOAD' TO FUNCTION-CODE.
    MOVE 'F' TO MODE-INDICATOR.
*            OPEN INDEX FILE FOR INTEGER COORDINATES.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK.
    MOVE +21 TO TRUE-USER-DATA-LENGTH.
    MOVE 'ISRT' TO FUNCTION-CODE.


010-OPEN-FILES.
    OPEN INPUT NTB-FILE.
    PERFORM 100-CONVERT-CALL-NTB THRU 100-EXIT
                                  UNTIL EOF.
    MOVE +9 TO TRUE-USER-DATA-LENGTH.
    PERFORM 200-OPEN-CLOSE-NDL-FILES THRU 200-EXIT
                         VARYING REV-NDX FROM 1 BY 1
                         UNTIL REV-NDX > 3.


900-LAST-CALL-TO-CARTOR.
    DISPLAY  'TOTAL # READS = '  TOTAL-GETS,
             ',  TOTAL # WRITES = '  TOTAL-PUTS,
          ',  TOTAL # INSERTS = '  TOTAL-ISRTS,  '.'.
    MOVE 'CLSE' TO FUNCTION-CODE.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK.


    GOBACK.


100-CONVERT-CALL-NTB.
    READ NTB-FILE
        AT  END
            MOVE 1 TO EOF-SWITCH
            CLOSE NTB-FILE
            GO TO 100-EXIT.
    MOVE V-IBLATLNG TO WK-LAT-LNG.
    MOVE V-NTB-KEY TO NTB-KEY.
    PERFORM 500-CONVERT-CALL THRU 500-EXIT.
100-EXIT.
    EXIT.
```

```
200-OPEN-CLOSE-NDL-FILES.
    MOVE REV-LETTER (REV-NDX) TO REV-FOR-DSN,
                                 DUMMY-DD-NAME-REV.
    CALL 'ALLOCD' USING RETURN-STATUS,
                        DD-NAME,
                        ALLOCATED-DSN,
                        DISPOSITION.
    IF SUCCESSFUL
        MOVE 0 TO EOF-SWITCH
        OPEN INPUT NDL-FILE
        PERFORM 300-CONVERT-CALL-NDL THRU 300-EXIT
                                     UNTIL EOF
        CALL 'DEALLC' USING RETURN-STATUS,
                            DD-NAME
        IF SUCCESSFUL
            NEXT SENTENCE
        ELSE
            DISPLAY 'STATUS = <', RETURN-STATUS,
                    '>, DDN = ', DD-NAME
            MOVE '0000' TO RETURN-STATUS
    ELSE
        DISPLAY 'STATUS = <',  RETURN-STATUS,
                '>, DDN = ', DD-NAME,
                ', DSN = ', ALLOCATED-DSN
        MOVE '0000' TO RETURN-STATUS.
    CALL 'DEALLC' USING RETURN-STATUS,
                        DUMMY-DD-NAME.
    IF  NOT SUCCESSFUL
        DISPLAY 'STATUS = <',  RETURN-STATUS,
                '>, DDN = ', DUMMY-DD-NAME
        MOVE '0000' TO RETURN-STATUS.
200-EXIT.
    EXIT.
```

```
300-CONVERT-CALL-NDL.
    READ NDL-FILE
        AT  END
            MOVE 1 TO EOF-SWITCH
            CLOSE NDL-FILE
            GO TO 300-EXIT.
    MOVE V-ZBLATLNG TO WK-LAT-LNG.
    MOVE V-ZBKEY TO NDL-IGZ.
    MOVE V-ZBREV TO REV OF NDL-KEY.
    PERFORM 500-CONVERT-CALL THRU 500-EXIT.
300-EXIT.
    EXIT.


500-CONVERT-CALL.
    COMPUTE NDX-LAT = (60 * WK-LATD + WK-LATM)
                                    * 60 + WK-LATS.
    IF  WK-LAT-DIR = 'S'
        COMPUTE NDX-LAT = - NDX-LAT.
    COMPUTE NDX-LON = (60 * WK-LONGD + WK-LONGM)
                                    * 60 + WK-LONGS.
    IF  WK-LONG-DIR = 'W'
        COMPUTE NDX-LON = - NDX-LON.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK,
                        USER-DATA-AREA,
                        COORDINATE-VECTOR.
    ADD NUMBER-VSAM-WRITES TO TOTAL-PUTS.
    ADD NUMBER-VSAM-READS  TO TOTAL-GETS.
    MOVE ZEROES TO NUMBER-VSAM-WRITES,
                   NUMBER-VSAM-READS.
    IF  SUCCESSFUL-CARTAM
        ADD ONE-CON TO TOTAL-ISRTS
    ELSE
        DISPLAY 'STATUS CODE = <' STATUS-CODE,
                '>,  KEY = <',
                 KEY-FEEDBACK-AREA '>.'.
500-EXIT.
    EXIT.
```

APPENDIX F

VSAM FILE DEFINITION EXAMPLE

```
//DFDLGEO  EXEC PGM=IDCAMS,REGION=256K
//STEPCAT  DD DISP=SHR,DSN=AMASTCAT
//SYSPRINT DD SYSOUT=A
//VSNTB    DD UNIT=3330,VOL=SER=VSAM02,SPACE=(TRK,1)
//SYSIN    DD *
    DEFINE CLUSTER(-
           NAME(VSAM.NTB.GEONDX)-
           FILE(VSNTB)-
           VOLUME(VSAM02)-
           CYLINDERS(15)-
           SHAREOPTIONS(1)-
           CISZ(4096)-
           NONINDEXED-
           RECORDSIZE(4089 4089)-
           SPEED-
           UNIQUE-
           OWNER(ADWNSD))-
           DATA(-
               NAME(VSAM.NTB.GEONDX.DATA))-
           CATALOG(AMASTCAT)
/*
```

APPENDIX G

CIRCLE SEARCH PROGRAM SOURCE

```
ID DIVISION.
PROGRAM-ID. ONETEME.
DATE-WRITTEN. MAY 77.
DATE-COMPILED.
REMARKS.


ENVIRONMENT DIVISION.

INPUT-OUTPUT SECTION.

FILE-CONTROL.
    SELECT COORD-FILE ASSIGN TO UT-S-DATAIN.
    SELECT PRINT-FILE ASSIGN TO UT-S-PRINTER.


DATA DIVISION.
FILE SECTION.


FD  COORD-FILE
    LABEL RECORDS ARE STANDARD
    BLOCK CONTAINS 0 RECORDS.
01  FILLER              PIC X(80).


FD  PRINT-FILE
    LABEL RECORDS ARE STANDARD
    BLOCK CONTAINS 0 RECORDS.
01  PRINT-REC           PIC X(132).
```

```
WORKING-STORAGE SECTION.

01  COMMUNICATION-BLOCK.
      COPY CARTCB07.

01  CONTROL-CARD.
    03  CNTRL-RADIUS       COMP-1 SYNC  VALUE +3.0E+3.
    03  CNTRLCRD-RADIUS-SECS COMP-1 SYNC.
    03  CNTRLCRD-RADIUS-IN-METERS COMP-1 SYNC.
    03  CNTRL-UNITS          PIC XX  VALUE 'MT'.
        88  NAUT-MILES               VALUE 'NM'.
        88  KILO-METERS              VALUE 'KM'.
        88  FEET                     VALUE 'FT'.
        88  METERS                   VALUE 'MT'.

    COPY CARTFNCS.

01  COORD-WORK-AREA.
    03  FILLER               PIC X(8) VALUE SPACES.
    03  ADN-NUMBER           PIC X(4) VALUE SPACES.
    03  FILLER               PIC X(21) VALUE SPACES.
    03  LAT-IN.
        05  LAT-DEG          PIC 99    VALUE ZEROS.
        05  LAT-MIN          PIC 99    VALUE ZEROS.
        05  LAT-SEC          PIC 99    VALUE ZEROS.
*       05  LAT-NS           PIC X     VALUE SPACES.
*           88  SOUTH        VALUE 'S'.
    03  LON-IN.
        05  LON-DEG          PIC 999   VALUE ZEROS.
        05  LON-MIN          PIC 99    VALUE ZEROS.
        05  LON-SEC          PIC 99    VALUE ZEROS.
        05  LON-EW           PIC X     VALUE SPACES.
            88  WEST         VALUE 'W'.
    03  FILLER               PIC X(33) VALUE SPACES.

01  KEY-FEEDBACK-AREA.
    05  NDL-KEY.
        10  ISL              PIC 9(5).
        10  DGZ              PIC X(3).
        10  REV              PIC X.
    05  FILLER               PIC X(15).
```

```
01  RESULT-AREA.
    03  INPUT-TO-OUTPUT.
        05  FILLER               PIC X(8)   VALUE SPACES.
        05  ADN-OUT              PIC X(4)   VALUE SPACES.
        05  FILLER               PIC X(68)  VALUE SPACES.
    03  FILLER                   PIC X(2)   VALUE SPACES.
    03  IGZ-OUT.
        05  REV                  PIC X.
        05  FILLER               PIC X.
        05  ISL                  PIC ZZZZ9.
        05  DGZ                  PIC XXX.
    03  FILLER                   PIC X(3)   VALUE SPACES.
    03  DIST-OUT          PIC ZZZ,ZZ9.9 VALUE '      0.0'.
    03  FILLER                   PIC X      VALUE SPACES.
    03  DIST-UNITS               PIC XX     VALUE SPACES.
    03  FILLER                   PIC X(26)  VALUE SPACES.


01  LIMIT-VECTORS.
    03  LOW-LIMITS.
        05  LOW-LAT               PIC S9(8) COMP SYNC.
        05  LOW-LON               PIC S9(8) COMP SYNC.
    03  HIGH-LIMITS.
        05  HIGH-LAT              PIC S9(8) COMP SYNC.
        05  HIGH-LON              PIC S9(8) COMP SYNC.


01  WORK-AREA.
    03  LATR            COMP-2 SYNC VALUE ZERO.
    03  LATO            PIC S9(8) COMP SYNC VALUE ZERO.
    03  LONO            PIC S9(8) COMP SYNC VALUE ZERO.
    03  CARTAM-COORDINATE-VECTOR.
        05  LAT1        PIC S9(8) COMP SYNC VALUE ZERO.
        05  LON1        PIC S9(8) COMP SYNC VALUE ZERO.
    03  DSTNCE1         COMP-1 SYNC VALUE ZERO.
    03  AZIMUTH1        COMP-1 SYNC VALUE 9.99E+02.
    03  DSTNCE2         COMP-1 SYNC VALUE ZERO.
    03  ESTIMATOR       COMP-1 SYNC VALUE 4.5E+01.
    03  NDX-DELTA       PIC S9(9) COMP SYNC.
    03  ANSWER-FACTOR COMP-1 SYNC VALUE ZERO.
    03  IFLAG           PIC S9(8) COMP SYNC VALUE +5.
    03  ONE-CON         PIC S9(8) COMP SYNC VALUE +1.
    03  MAX-H-G-CELLS PIC S9(8) COMP SYNC VALUE +100.
    03  SECRAD         COMP-1  SYNC VALUE .48481368E-05.
    03  NUM-ADNS        PIC S9(4) COMP VALUE +1000.
    03  NONE-FLAG     PIC X          VALUE LOW-VALUES.
        88  NONE-IN VALUE HIGH-VALUES.
```

```
01  HISTO-GRAM   SYNC.
    03  H-G-MIN               PIC S9(8) COMP.
    03  H-G-MAX               PIC S9(8) COMP.
    03  H-G-CELL-ZERO         PIC S9(8) COMP.
    03  H-G-CELLS    PIC S9(8) COMP OCCURS 100 TIMES.
    03  H-G-CELL-MAX          PIC S9(8) COMP.


LINKAGE SECTION.
01  PARM-FIELD.
    03  PARM-LENGTH           PIC  9(4) COMP.
        88  VALID-PARM-PASSED  VALUE 7.
    03  PARM-RADIUS           PIC  9(5).
    03  PARM-UNITS            PIC XX.
    03  PARM-BUFFERS          PIC 99.
    03  PARM-NUM-ADNS         PIC 999.
```

```
PROCEDURE DIVISION  USING PARM-FIELD.


0000-DRIVER.
    MOVE 24 TO MAX-USER-AREA-LENGTH.
    MOVE CARTAM-OPEN TO FUNCTION-CODE.
    IF PARM-LENGTH NOT < 9
       MOVE PARM-BUFFERS TO MAX-NUMBER-BUFFERS.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK.
    IF NOT GOOD-CARTAM-OPEN
        DISPLAY 'BAD OPEN RETURN CODE'
        GOBACK.
    OPEN INPUT COORD-FILE
         OUTPUT PRINT-FILE.
    MOVE ALL LOW-VALUES TO HISTO-GRAM.
    MOVE +1000000 TO H-G-MIN.
    IF PARM-LENGTH NOT < 7
       MOVE PARM-RADIUS TO CNTRL-RADIUS
       MOVE PARM-UNITS TO CNTRL-UNITS.
    IF PARM-LENGTH NOT < 12
       MOVE PARM-NUM-ADNS TO NUM-ADNS.
    IF NAUT-MILES
        COMPUTE CNTRLCRD-RADIUS-SECS = 60.0 *
               (CNTRL-RADIUS)
        MOVE +1852.0 TO ANSWER-FACTOR
    ELSE
        IF KILO-METERS
            COMPUTE CNTRLCRD-RADIUS-SECS = 60.0 *
                   (CNTRL-RADIUS / 1.852)
            MOVE +1000.0 TO ANSWER-FACTOR
        ELSE
            IF FEET
                COMPUTE CNTRLCRD-RADIUS-SECS = 60.0 *
                       (CNTRL-RADIUS / 6080.0)
                MOVE +0.3048 TO ANSWER-FACTOR
            ELSE
                COMPUTE CNTRLCRD-RADIUS-SECS = 60.0 *
                       (CNTRL-RADIUS / 1852.0)
                MOVE +1.0 TO ANSWER-FACTOR.
    COMPUTE CNTRLCRD-RADIUS-IN-METERS =
            CNTRL-RADIUS * ANSWER-FACTOR.
```

```
0100-PROCESS-LOOP.
    READ COORD-FILE INTO COORD-WORK-AREA
        AT END  GO TO 0100-FINISH-UP.
    MOVE CNTRLCRD-RADIUS-SECS TO HIGH-LON.
    MULTIPLY HIGH-LON BY +1.1 GIVING HIGH-LAT.
    COMPUTE LATO = (LAT-DEG * 60 + LAT-MIN) * 60
                   + LAT-SEC.
*   IF SOUTH  COMPUTE LATO = - LATO.
    COMPUTE LONO = (LON-DEG * 60 + LON-MIN) * 60
                   + LON-SEC.
    IF WEST  COMPUTE LONO = - LONO.
    COMPUTE LATR = LATO * SECRAD.
    CALL 'HAFSID' USING LATR, HIGH-LON.
    COMPUTE  LOW-LAT = LATO - HIGH-LAT.
    COMPUTE  LOW-LON = LONO - HIGH-LON.
    COMPUTE  HIGH-LAT = LATO + HIGH-LAT.
    COMPUTE  HIGH-LON = LONO + HIGH-LON.
    WRITE PRINT-REC FROM COORD-WORK-AREA
                    AFTER ADVANCING 3 LINES.
    MOVE SPACES TO RESULT-AREA.
    MOVE CNTRL-UNITS TO DIST-UNITS.
    MOVE ADN-NUMBER TO ADN-OUT.
    MOVE HIGH-VALUES TO NONE-FLAG.
    MOVE ZERO TO NUMBER-VSAM-READS.
    MOVE GR TO FUNCTION-CODE.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK,
                        KEY-FEEDBACK-AREA,
                        CARTAM-COORDINATE-VECTOR,
                        NDX-DELTA,
                        LOW-LIMITS,
                        HIGH-LIMITS.
    PERFORM 0200-WALK-PATH THRU 0200-WALK-PATH-EXIT
        UNTIL NOT MORE-PATH.
    IF NONE-IN
        MOVE CNTRL-RADIUS TO DIST-OUT
        MOVE 'NONE IN ' TO IGZ-OUT
        WRITE PRINT-REC FROM RESULT-AREA.
    IF NUMBER-VSAM-READS > H-G-MAX
        MOVE NUMBER-VSAM-READS TO H-G-MAX.
    IF NUMBER-VSAM-READS < H-G-MIN
        MOVE NUMBER-VSAM-READS TO H-G-MIN.
    IF NUMBER-VSAM-READS < ONE-CON
        ADD ONE-CON TO H-G-CELL-ZERO
    ELSE
        IF NUMBER-VSAM-READS > MAX-H-G-CELLS
            ADD +1 TO H-G-CELL-MAX
        ELSE
            ADD +1 TO H-G-CELLS (NUMBER-VSAM-READS).
    SUBTRACT 1 FROM NUM-ADNS.
    IF NUM-ADNS > 0
        GO TO 0100-PROCESS-LOOP.
```

```
0100-FINISH-UP.
    DISPLAY 'MIN # READS = ', H-G-MIN,
         ';  MAX # READS = ', H-G-MAX,
         ';  CELL(0) = ', H-G-CELL-ZERO,
         ';  CELL(101) = ', H-G-CELL-MAX.
    IF H-G-MAX > 100
        MOVE +100 TO H-G-MAX.
    PERFORM H-G-DISPLAY  VARYING NUMBER-VSAM-READS
       FROM 1 BY 1 UNTIL NUMBER-VSAM-READS > H-G-MAX.
    MOVE CARTAM-CLOSE TO FUNCTION-CODE.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK.
    CLOSE COORD-FILE
          PRINT-FILE.
    GOBACK.


H-G-DISPLAY.
    DISPLAY '  CELL(', NUMBER-VSAM-READS, ') = ',
              H-G-CELLS (NUMBER-VSAM-READS).
```

```
0200-WALK-PATH.
    MOVE GNP TO FUNCTION-CODE.
    MULTIPLY NDX-DELTA BY ESTIMATOR GIVING DSTNCE2.
    CALL 'VECTOR' USING LAT1 LON1
                        LAT0 LON0
                        DSTNCE1          IFLAG.
    SUBTRACT CNTRLCRD-RADIUS-IN-METERS FROM DSTNCE1.
    IF DSTNCE2 < DSTNCE1
      MOVE 88-DISCARD-SUBTREE TO FUNCTION-CODE-4
    ELSE
      IF DSTNCE2 NOT > - DSTNCE1
        MOVE 88-KEEP-ALL-CHILDREN TO FUNCTION-CODE-4
        PERFORM 0300-KEEP-ALL THRU 0300-KEEP-ALL-EXIT
                UNTIL NOT MORE-PATH
        MOVE 88-CONTINUE-WALK TO FUNCTION-CODE-4.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK,
                        KEY-FEEDBACK-AREA,
                        CARTAM-COORDINATE-VECTOR,
                        NDX-DELTA.
0200-WALK-PATH-EXIT.
    EXIT.


0300-KEEP-ALL.
    IF TRUE-USER-DATA-LENGTH = 9
        CALL 'VECTOR' USING LAT0 LON0
                            LAT1 LON1
                            DSTNCE1 IFLAG
        MOVE CORR NDL-KEY TO IGZ-OUT
        DIVIDE DSTNCE1 BY ANSWER-FACTOR
                       GIVING DIST-OUT
        MOVE LOW-VALUES TO NONE-FLAG
        WRITE PRINT-REC FROM RESULT-AREA
                        AFTER ADVANCING 1 LINE.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK,
                        KEY-FEEDBACK-AREA,
                        CARTAM-COORDINATE-VECTOR,
                        NDX-DELTA.
0300-KEEP-ALL-EXIT.
    EXIT.
```

APPENDIX H

INCLUSION/EXCLUSION AREA SEARCH PROGRAM SOURCE

```
ID DIVISION.
PROGRAM-ID. XCLUDOR2.
DATE-WRITTEN. MAY 77.
DATE-COMPILED.
REMARKS.


ENVIRONMENT DIVISION.

INPUT-OUTPUT SECTION.

FILE-CONTROL.
    SELECT CNTRLCRD ASSIGN TO UT-S-CONTROL.
    SELECT LAUNCH-POINT-FILE ASSIGN TO UT-S-LAUNCH.
    SELECT SORTED-FILE ASSIGN TO UT-S-SRTNULL.
    SELECT SORTED-OUTPUT-FILE ASSIGN TO UT-S-NTBS.
```

```
DATA DIVISION.

FILE SECTION.

SD   SORTED-FILE.
01   SELECTED-RECORD.
     03  PRIMARY-KEY         PIC X(21).
     03  FILLER              PIC X(15).

FD   CNTRLCRD
     LABEL RECORDS ARE STANDARD
     BLOCK CONTAINS 0 RECORDS.
01   FILLER             PIC X(80).

FD   LAUNCH-POINT-FILE
     LABEL RECORDS ARE STANDARD
     RECORD CONTAINS 21 CHARACTERS
     BLOCK CONTAINS 0 RECORDS.
01   LP-DATA            PIC X(21).
*                 READ INTO LP-DATA-AREA.

FD   SORTED-OUTPUT-FILE
     LABEL RECORDS ARE STANDARD
     BLOCK CONTAINS 0 RECORDS.
01   OUT-REC-S          PIC X(36).



WORKING-STORAGE SECTION.

01   SIXTY                   PIC S9(8) COMP SYNC VALUE +60.
01   COMMUNICATION-BLOCK.    COPY CARTCB07.

01   NDX-VECTORS.
     05  NDX-LAT             PIC S9(8)      COMP SYNC.
     05  NDX-LON             PIC S9(8)      COMP SYNC.
     05  NDX-DELTA           PIC S9(8)      COMP SYNC.

01   LIMIT-VECTORS.
     05  LOW-LIMITS.
         10  LOW-LAT         PIC S9(8)      COMP SYNC.
         10  LOW-LON         PIC S9(8)      COMP SYNC.
     05  HIGH-LIMITS.
         10  HIGH-LAT        PIC S9(8)      COMP SYNC.
         10  HIGH-LON        PIC S9(8)      COMP SYNC.
```

```
 01  CNTRLCRD-IN.
*    COLS          1         2         3         4         5
*        12345678901234567890123456789012345678901234567890
*        >      2500KM      55N+/-25 090E+/-090     ISLE#ISLE#
*                           LAT       LONG            LOW   HIGH
     03  FILLER                 PIC X.
         88  EXCLUSION-AREA-SEARCH  VALUE '>'.
         88  INCLUSION-AREA-SEARCH  VALUE '<'.
     03  FILLER                 PIC X(4).
     03  CNTRL-RADIUS           PIC 9(5).
     03  CNTRL-UNITS            PIC XX.
         88  NAUT-MILES                 VALUE 'NM'.
         88  KILO-METERS                VALUE 'KM'.
         88  FEET                       VALUE 'FT'.
         88  METERS                     VALUE 'MT'.
     03  FILLER                 PIC X(5).
     03  CNTRL-CENTER-LAT-DEG PIC 99.
     03  FILLER                 PIC X.
         88  CNTRL-SOUTH                VALUE 'S'.
     03  FILLER                 PIC XXX VALUE '+/-'.
     03  CNTRL-DELTA-LAT        PIC 99.
     03  FILLER                 PIC X.
     03  CNTRL-CENTER-LON-DEG PIC 999.
     03  FILLER                 PIC X.
         88  CNTRL-WEST                 VALUE 'W'.
     03  FILLER                 PIC XXX VALUE '+/-'.
     03  CNTRL-DELTA-LON        PIC 999.
     03  FILLER                 PIC X(4).
     03  MIN-ISLE               PIC 9(5).
     03  MAX-ISLE               PIC 9(5).
     03  FILLER                 PIC X(3).
     03  LP-DATA-AREA.
         05  LATD               PIC 99.
         05  LATM               PIC 99.
         05  LATS               PIC 99.
         05  NS-DIR             PIC X.
                 88 LP-SOUTH            VALUE 'S'.
         05  FILLER             PIC X.
         05  LOND               PIC 999.
         05  LONM               PIC 99.
         05  LONS               PIC 99.
         05  EW-DIR             PIC X.
                 88 LP-WEST             VALUE 'W'.
         05  LP-RADIUS          PIC 9(5).
     03  FILLER                 PIC X(6).
 01  CNTRLCRD-TRANSFORM REDEFINES CNTRLCRD-IN PIC X(80).


     COPY CARTFNCS.
```

```
01  RESULT-AREA.
    03  KEY-OUT.
        05  ISL                 PIC 9(5).
        05  FILLER              PIC X(16).
    03  LAT-OUT.
        05  LAT-DEG             PIC 99    VALUE ZEROS.
        05  LAT-MIN             PIC 99    VALUE ZEROS.
        05  LAT-SEC             PIC 99    VALUE ZEROS.
        05  LAT-NS              PIC X     VALUE SPACES.
    03  LON-OUT.
        05  LON-DEG             PIC 999   VALUE ZEROS.
        05  LON-MIN             PIC 99    VALUE ZEROS.
        05  LON-SEC             PIC 99    VALUE ZEROS.
        05  LON-EW              PIC X     VALUE SPACES.


01  WORK-AREA.
    03  LATR                     COMP-2 SYNC VALUE ZERO.
    03  MAXIMUM-RADIUS-IN-METERS  COMP-1 SYNC.
    03  CNTRLCRD-RADIUS-IN-METERS COMP-1 SYNC.
    03  ABS-LAT             PIC  9(8) COMP SYNC VALUE ZERO.
    03  DSTNCE1             COMP-1 SYNC VALUE ZERO.
    03  SECRAD              COMP-1 SYNC VALUE .48481368E-05.
    03  DSTNCE2             COMP-1 SYNC VALUE ZERO.
    03  ESTIMATOR           COMP-1 SYNC VALUE 4.5E+01.
    03  LAT-LNG-WORK-AREA PIC S9(8) COMP SYNC VALUE ZERO.
    03  IFLAG             PIC S9(8) COMP SYNC VALUE +5.
    03 TOTAL-NUMBER-READS PIC S9(6) COMP SYNC VALUE ZERO.
    03  MIN-ISLE-NUMBER   PIC 9(5) COMP-3 VALUE ZERO.
    03  MAX-ISLE-NUMBER   PIC 9(5) COMP-3 VALUE ZERO.
    03  NUMBER-RECORDS    PIC 9(5) COMP-3 VALUE ZERO.
    03  NONE-FLAG         PIC X   VALUE LOW-VALUES.
        88  NONE-IN               VALUE HIGH-VALUES.
    03  OUTSIDE-ALL-CIRCLES PIC X   VALUE SPACE.
    03  INSIDE-A-CIRCLE     PIC X   VALUE SPACE.
    03  LP-END-FLAG         PIC XXX VALUE SPACES.
        88  END-OF-LPS              VALUE 'END'.
    03  NUMBER-OF-LAUNCH-POINTS    USAGE INDEX.


01  LAUNCH-POINT-DATA SYNC.
    03 LP-TABLE OCCURS 100 TIMES INDEXED BY LAUNCH-POINT.
        05  LP-LAT          PIC S9(8) SYNC COMP.
        05  LP-LON          PIC S9(8) SYNC COMP.
        05  LP-DELTA-LAT    PIC S9(8) SYNC COMP.
        05  LP-DELTA-LON    PIC S9(8) SYNC COMP.
        05  LP-RADIUS-IN-METERS        SYNC COMP-1.
```

```
PROCEDURE DIVISION.


0000-DRIVER.
    CALL 'TIMEAX' USING INTERVAL.
    MOVE 21 TO MAX-USER-AREA-LENGTH.
    MOVE CARTAM-OPEN TO FUNCTION-CODE.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK.
    IF NOT GOOD-CARTAM-OPEN
        DISPLAY 'BAD OPEN RETURN CODE'
        GOBACK.
    OPEN INPUT CNTRLCRD.


0000-CNTL-LOOP.
    READ CNTRLCRD INTO CNTRLCRD-IN
        AT END  MOVE CARTAM-CLOSE TO FUNCTION-CODE
                CALL 'CARTAM' USING COMMUNICATION-BLOCK
                CLOSE CNTRLCRD
                GOBACK.
    TRANSFORM CNTRLCRD-TRANSFORM FROM SPACES TO ZEROES.
    MOVE MIN-ISLE TO MIN-ISLE-NUMBER.
    MOVE MAX-ISLE TO MAX-ISLE-NUMBER.
    MULTIPLY CNTRL-CENTER-LAT-DEG BY 3600 GIVING NDX-LAT.
    IF CNTRL-SOUTH  COMPUTE NDX-LAT = - NDX-LAT.
    MULTIPLY CNTRL-DELTA-LAT BY 3600 GIVING NDX-DELTA.
    COMPUTE LOW-LAT = NDX-LAT - NDX-DELTA.
    COMPUTE HIGH-LAT = NDX-LAT + NDX-DELTA.
    MULTIPLY CNTRL-CENTER-LON-DEG BY 3600 GIVING NDX-LON.
    IF CNTRL-WEST  COMPUTE NDX-LON = - NDX-LON.
    MULTIPLY CNTRL-DELTA-LON BY 3600 GIVING NDX-DELTA.
    COMPUTE LOW-LON = NDX-LON - NDX-DELTA.
    COMPUTE HIGH-LON = NDX-LON + NDX-DELTA.
    MOVE CNTRL-RADIUS TO LP-RADIUS.
    MOVE ZEROS TO CNTRLCRD-RADIUS-IN-METERS,
                  MAXIMUM-RADIUS-IN-METERS,
                  NUMBER-RECORDS.
    IF INCLUSION-AREA-SEARCH
        MOVE 88-DISCARD-SUBTREE   TO OUTSIDE-ALL-CIRCLES
        MOVE 88-KEEP-ALL-CHILDREN TO INSIDE-A-CIRCLE
    ELSE
        MOVE 88-KEEP-ALL-CHILDREN TO OUTSIDE-ALL-CIRCLES
        MOVE 88-DISCARD-SUBTREE   TO INSIDE-A-CIRCLE.
    SET LAUNCH-POINT TO 1.
    PERFORM 0010-CNVRT-COORDS THRU 0010-EXIT.
    MOVE MAXIMUM-RADIUS-IN-METERS
                          TO CNTRLCRD-RADIUS-IN-METERS.
    MOVE ZERO TO MAXIMUM-RADIUS-IN-METERS

    IF LP-LAT (1) = ZERO
        OPEN INPUT LAUNCH-POINT-FILE
```

```
        PERFORM 0010-READ-LAUNCH-POINTS THRU 0010-EXIT
            VARYING LAUNCH-POINT FROM 1 BY 1
            UNTIL (LAUNCH-POINT > 100) OR END-OF-LPS
        CLOSE LAUNCH-POINT-FILE.
    MOVE HIGH-VALUES TO NONE-FLAG.
    MOVE GR TO FUNCTION-CODE.
    SORT SORTED-FILE ON ASCENDING KEY PRIMARY-KEY
             INPUT PROCEDURE CARTAM-RETRIEVAL
             GIVING SORTED-OUTPUT-FILE.


    DISPLAY 'FINAL STATUS = ', STATUS-CODE,
            ';  NUM READS = ', NUMBER-VSAM-READS,
            ';     # INSTS = ', NUMBER-RECORDS.
    GO TO 0000-CNTL-LOOP.


0010-READ-LAUNCH-POINTS.
    READ LAUNCH-POINT-FILE
        AT END
            MOVE 'END' TO LP-END-FLAG
            GO TO 0010-EXIT.
    TRANSFORM LP-DATA FROM SPACES TO ZEROS.
    MOVE LP-DATA TO LP-DATA-AREA.
```

```
0010-CNVRT-COORDS.
    SET NUMBER-OF-LAUNCH-POINTS TO LAUNCH-POINT.
    IF LP-RADIUS = ZERO
      MOVE CNTRLCRD-RADIUS-IN-METERS TO
                 LP-RADIUS-IN-METERS (LAUNCH-POINT)
    ELSE
      IF NAUT-MILES
        COMPUTE LP-RADIUS-IN-METERS (LAUNCH-POINT) =
                LP-RADIUS * 1852.0
      ELSE
        IF KILO-METERS
          COMPUTE LP-RADIUS-IN-METERS (LAUNCH-POINT) =
                  LP-RADIUS * 1000.0
        ELSE
          IF FEET
            COMPUTE LP-RADIUS-IN-METERS (LAUNCH-POINT) =
                    LP-RADIUS * 0.3048
          ELSE
            MOVE LP-RADIUS
              TO LP-RADIUS-IN-METERS (LAUNCH-POINT).
    IF LP-RADIUS-IN-METERS (LAUNCH-POINT)
                            > MAXIMUM-RADIUS-IN-METERS
        MOVE LP-RADIUS-IN-METERS (LAUNCH-POINT)
                             TO MAXIMUM-RADIUS-IN-METERS.
    COMPUTE LP-LAT (LAUNCH-POINT)
        = ((LATD * 60 + LATM) * 60 + LATS).
    IF LP-SOUTH
        COMPUTE LP-LAT (LAUNCH-POINT)
            = - LP-LAT (LAUNCH-POINT).
    COMPUTE LP-LON (LAUNCH-POINT)
        = ((LOND * 60 + LONM) * 60 + LONS).
    IF LP-WEST
        COMPUTE LP-LON (LAUNCH-POINT)
            = - LP-LON (LAUNCH-POINT).
    COMPUTE LP-DELTA-LAT (LAUNCH-POINT) ROUNDED =
            34 * LP-RADIUS-IN-METERS (LAUNCH-POINT).
    MOVE LP-LAT (LAUNCH-POINT) TO ABS-LAT.
    IF ABS-LAT + LP-DELTA-LAT (LAUNCH-POINT) < 324000
        COMPUTE LATR ROUNDED
              = LP-LAT (LAUNCH-POINT) * SECRAD
        CALL 'HAFSID' USING LATR,
                          LP-DELTA-LON (LAUNCH-POINT)
    ELSE
        MOVE 1500000 TO LP-DELTA-LON (LAUNCH-POINT).

0010-EXIT.
    EXIT.
```

```
CARTAM-RETRIEVAL SECTION.

WALK-RETRIEVAL-PATH.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK,
                        KEY-OUT,
                        NDX-VECTORS,
                        NDX-DELTA,
                        LOW-LIMITS,
                        HIGH-LIMITS.
    IF NOT MORE-PATH
        GO TO CARTAM-RETRIEVAL-EXIT
    ELSE
        MOVE GNP TO FUNCTION-CODE
        MOVE NDX-LAT TO ABS-LAT
        IF (ABS-LAT + NDX-DELTA) NOT > 324000
*                INITIALIZE TO OUTSIDE-ALL
            MOVE OUTSIDE-ALL-CIRCLES TO FUNCTION-CODE-4
           MULTIPLY NDX-DELTA BY ESTIMATOR GIVING DSTNCE2
            PERFORM 0200-CHK-LPS THRU 0200-CHK-LPS-EXIT
                VARYING LAUNCH-POINT FROM 1 BY 1 UNTIL
                (LAUNCH-POINT > NUMBER-OF-LAUNCH-POINTS)
            IF KEEP-ALL-CHILDREN
                PERFORM 0300-KEEP-ALL THRU
                   0300-KEEP-ALL-EXIT UNTIL NOT MORE-PATH
                IF STATUS-CODE = 'GM'
                    MOVE 88-CONTINUE-WALK TO
                                  TO FUNCTION-CODE-4
                    MOVE SPACES TO STATUS-CODE.

    GO TO WALK-RETRIEVAL-PATH.
```

```
 0200-CHK-LPS.
     COMPUTE ABS-LAT = NDX-LAT - LP-LAT (LAUNCH-POINT).
     IF ABS-LAT NOT >
              NDX-DELTA + LP-DELTA-LAT (LAUNCH-POINT)
         COMPUTE ABS-LAT = NDX-LON - LP-LON (LAUNCH-POINT)
         IF ABS-LAT NOT >
                   NDX-DELTA + LP-DELTA-LON (LAUNCH-POINT)
             CALL 'VECTOR' USING NDX-LAT
                                 NDX-LON
                                 LP-LAT (LAUNCH-POINT)
                                 LP-LON (LAUNCH-POINT)
                                 DSTNCE1 IFLAG
             SUBTRACT LP-RADIUS-IN-METERS (LAUNCH-POINT)
                                           FROM DSTNCE1
             IF DSTNCE2 NOT > - DSTNCE1
*                   TOTALLY INSIDE A RANGE CIRCLE
                 MOVE INSIDE-A-CIRCLE TO FUNCTION-CODE-4
                 SET LAUNCH-POINT
                            TO NUMBER-OF-LAUNCH-POINTS
             ELSE
                 IF DSTNCE2 > DSTNCE1
*                       OVERLAPS A RANGE CIRCLE
                     MOVE 88-CONTINUE-WALK
                                  TO FUNCTION-CODE-4
                     IF DSTNCE2 > MAXIMUM-RADIUS-IN-METERS
                         SET LAUNCH-POINT TO
                             NUMBER-OF-LAUNCH-POINTS.
 0200-CHK-LPS-EXIT.
     EXIT.
```

```
0300-KEEP-ALL.
    IF (NOT NODE) AND (ISL NOT < MIN-ISLE-NUMBER
                              AND NOT > MAX-ISLE-NUMBER)
        MOVE LOW-VALUES TO NONE-FLAG
        PERFORM 0350-EXPAND-COORDS
           THRU 0350-EXPAND-COORDS-EXIT
        RELEASE SELECTED-RECORD FROM RESULT-AREA
        ADD +1 TO NUMBER-RECORDS.
    CALL 'CARTAM' USING COMMUNICATION-BLOCK,
                        KEY-OUT,
                        NDX-VECTORS,
                        NDX-DELTA.
0300-KEEP-ALL-EXIT.
    EXIT.



0350-EXPAND-COORDS.
    IF NDX-LAT < 0
        COMPUTE LAT-LNG-WORK-AREA = - NDX-LAT
        MOVE 'S' TO LAT-NS OF LAT-OUT
    ELSE
        MOVE NDX-LAT TO LAT-LNG-WORK-AREA
        MOVE 'N' TO LAT-NS OF LAT-OUT.
    DIVIDE LAT-LNG-WORK-AREA BY SIXTY
            GIVING LAT-LNG-WORK-AREA
            REMAINDER LAT-SEC OF LAT-OUT.
    DIVIDE LAT-LNG-WORK-AREA BY SIXTY
            GIVING LAT-DEG OF LAT-OUT
            REMAINDER LAT-MIN OF LAT-OUT.
    IF NDX-LON < 0
        COMPUTE LAT-LNG-WORK-AREA = - NDX-LON
        MOVE 'W' TO LON-EW OF LON-OUT
    ELSE
        MOVE NDX-LON TO LAT-LNG-WORK-AREA
        MOVE 'E' TO LON-EW OF LON-OUT.
    DIVIDE LAT-LNG-WORK-AREA BY SIXTY
            GIVING LAT-LNG-WORK-AREA
            REMAINDER LON-SEC OF LON-OUT.
    DIVIDE LAT-LNG-WORK-AREA BY SIXTY
            GIVING LON-DEG OF LON-OUT
            REMAINDER LON-MIN OF LON-OUT.
0350-EXPAND-COORDS-EXIT.
    EXIT.



CARTAM-RETRIEVAL-EXIT.
    EXIT.
```

APPENDIX I

FORTRAN SUBROUTINE TO EXPAND LONGITUDE

```
SUBROUTINE HAPSID (ALAT, ISID)
ISID = ABS(1.1*ISID/COS(ALAT))
RETURN
END
```