Suitability of Ada for Real-Time Model Based Vision Applications

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November 1991

Final Report for Period July 90 to July 91

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The purpose of this study was to establish a baseline for assessing the execution efficiency of Model Based Vision (MBV) algorithms coded in both the Ada and C programming languages. To facilitate this study a key algorithm used in The Analytic Science Corporation's (TASC) laboratory MBV system called Fast Pairwise Nearest Neighbor (FASTPNN) was recoded from its original C form to Ada, and benchmarked on both a VAX 11/780 and MIPS MAGNUM 3000 computer system. Comparisons of C execution efficiency versus Ada execution efficiency as well as MIPS MAGNUM 3000 execution efficiency versus VAX 11/780 execution efficiency were made. The benchmark results indicate that when Ada run-time checks are suppressed, Ada and C are roughly equivalent in terms of inherent execution efficiency. Differences between Ada and C execution efficiency can be attributed to deviations in a particular compiler's maturity. Ada run-time checks impose between a 43% and 65% execution penalty when compared with Ada executing with all run-time checks suppressed. Depending on whether C or Ada was the language of interest, the MIPS MAGNUM 3000 demonstrated between a 9 (Ada) to 22 (C) times throughput advantage over the VAX 11/780.
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1. INTRODUCTION. The purpose of this study was to establish a baseline for assessing the execution efficiency of Model Based Vision (MBV) algorithms coded in both the Ada and C programming languages. Model-based vision systems compare predictions of target signature in sensed data with information extracted from sensed data to achieve target recognition. To date, prediction of electromagnetic signature for Synthetic Aperture Radar (SAR) is the emphasized sensed data. Under contract with Wright Laboratory, The Analytic Science Corporation (TASC) has extracted algorithms from their MBV system and delivered them to the Government. The algorithms delivered to the Government are to be used as benchmarks for evaluating the performance of different processors for MBV applications. All of the algorithms delivered are coded in the C programming language.

To evaluate the suitability of Ada for MBV applications, an important MBV algorithm from the TASC MBV system, called Fast Pairwise Nearest Neighbor (FASTPNN), was translated in its original C form to Ada and benchmarked on both a VAX 11/780 and MIPS Magnum 3000 computer. While the FASTPNN algorithm comprises only a small subset of the entire TASC MBV system, in terms of the general types of processing requirements it imposes, it is representative of a significant portion of the TASC MBV system.
2. DESCRIPTION OF PAIRWISE NEAREST NEIGHBOR ALGORITHM.

The Pairwise Nearest Neighbor (PNN) algorithm is a vector quantization procedure used inside the information extraction portion of the TASC MBV system. The PNN algorithm is used to represent the significant characteristics of a large number of image samples (or vectors) with a smaller specified number of vectors such that the derived set of vectors represent the original set of vectors as "best" as possible with respect to coordinate position and weight (gray level). The PNN algorithm derives a specified number of quantization vectors by progressively merging together pairs of vectors with minimal weighted distance between their centroids.

The TASC MBV system uses a vector quantizer which consists of the FASTPNN vector quantizer cascaded with a Linde-Buzo-Gray (LBG) vector quantizer. The LBG vector quantizer is an iterative algorithm that produces a set of quantization vectors that minimize mean square quantization error; however the algorithm tends to converge to local minima unless good estimates for initial quantization vectors are available. The PNN vector quantizer provides a near optimal set of quantization vectors, that support the functional needs of the LBG algorithm.

2.1 Full Search Implementation of PNN Algorithm

The key to quick execution of the PNN algorithm is quickly finding the closest pairs of entries (vectors) among the distributed set. Figure 1 describes the sequence of operations in the full search implementation of PNN. Figure 1 shows that the full search implementation of PNN is an iterative procedure where on each iteration the pair of vectors which generates the least error when merged (the closest pair) is merged. The algorithm explicitly requires that, at each iteration, each vector's nearest neighbor be found. The calculation to determine the closest vector pair is essentially a weighted distance calculation where the distance between the two vectors are weighted by the gray level (or weight) of each of the two vectors. The new vector is chosen to minimize the error incurred by replacing the two original vectors into one new vector.

In general, the number of distance calculations to find the two closest vectors among a randomly distributed set is given by

\[
\text{DIST\_CALC} = \frac{(N \times (N-1))}{2} \quad (1)
\]

where DIST\_CALC is the number of permutations of distance calculations required and N is the number of entries (vectors). Thus, if one were to initiate a full search PNN with 1000 entries, then the first iteration would require 499,500 distance calculations to find the closest vector pair for merging. Once the first iteration was completed, the following iterations would require much fewer distance calculations to find the closest vector pairs since only the distances from the "new" vector to each of the remaining entries would need to be recalculated. The distance calculations among the remaining entries would not need to be recalculated. Thus, in our example, only 999
Determine the pair of vectors from data set which generates the least error when merged

Merge the pair which generates the least error when merged

Does the number of entries remaining equal the desired number of quantization vectors?

Yes, done

No

Figure 1. Block Diagram of Full Search PNN
distance calculations would be required on the second iteration, and 998
iterations required on the third iteration. This procedure continues
iteratively until the desired number of quantization vectors are
reached. Thus, the total number of distance calculations is given by

\[ \text{TOT DIST CALC} = N(N-1)/2 + N-1 + N-2 + \ldots P \] (2)

where \( \text{TOT DIST CALC} \) is the total number of distance calculations
required, \( N \) is the input data size, and \( P \) is the desired number of
quantization vectors.

The first term on the right hand side (RHS) of equation (2) dominates
the equation and it is obvious that the full search implementation of
PNN has computational requirement proportional to \( O(N^2) \).

2.2 Fast Implementation of PNN Algorithm

If the requirement to merge the absolute closest pair of vectors at
each step is relaxed, as long as vectors get merged eventually then a
fast implementation of the PNN algorithm can be derived (Reference 2).
This approximated PNN algorithm is called the "fast" PNN (FASTPNN)
algorithm. For most applications the error introduced by the FASTPNN
approximation of PNN is considered tolerable (reference). The "fast"
implementation of PNN was used in this study.

Figure 2 describes the sequence of operations in FASTPNN. The FASTPNN
algorithm initially constructs a set of entries from the input data,
then iteratively merges pairs of entries until a specified number of
quantization vectors are reached. At each iteration, the algorithm
proceeds by recursively splitting sets of entries, or buckets, into
pairs of buckets until the total number of entries in each bucket is
at or below a prespecified number. From each bucket, a candidate pair
of entries is nominated that, if merged, provide the smallest increase
in quantization error of all pairs within the bucket. A specified
percentage of the pairs are selected and merged, with the individual
buckets merged into a single bucket to complete an iteration. The
sequence is repeated until the total number of entries is equal to the
specified number of quantization vectors. The value vectors in the
final set of entries define the derived quantization vectors.

The computational savings in FASTPNN is derived in the algorithm’s
ability to "intelligently" split the global data set among a specified
number of localized regions or buckets. Merging of vectors are then
performed independently and with more efficiency within these localized
regions (buckets).

A key parameter in FASTPNN is BUCKETSIZER, the maximum number of vectors
per bucket. BUCKETSIZER plays a key role in determining the number of
distance calculations involved in finding the closest vector pair.
Since FASTPNN requires that the data be split evenly across all buckets
then the total number of buckets required for a particular iteration
equals the number of input vectors divided by BUCKETSIZER.

\[ \text{BUCKET NUM} = \frac{N}{\text{BUCKETSIZER}} \] (3)
Figure 2. Block Diagram of FASTPNN Algorithm
where BUCKET NUM equals the total number of buckets for a data set of size N, and bucket containing BUCKETSIZE entries. From equation (1), to find the closest vector pair in each particular bucket requires that 

\[ \text{(BUCKETSIZE} \times (\text{BUCKETSIZE} - 1)/2 \text{)} \] 

weighted distance calculations be performed. Thus, the total number of distance calculations for the complete data set on the first iteration equals the number of distance calculations per bucket times the number of buckets, or

\[ \text{DIST}\_\text{CALC} = (\text{BUCKETSIZE} \times (\text{BUCKETSIZE} - 1)/2) \times \text{N/BUCKETSIZE} \quad (4) \]

Equation (4) reduces to

\[ \text{DIST}\_\text{CALC} = \text{N} \times (\text{BUCKETSIZE} - 1)/2 \quad (5) \]

where DIST CALC is the total number of distance calculations required on the first iteration of FASTPNN. Thus, it is readily seen from equation 5 that as BUCKETSIZE decreases the number of calculations goes proportionally down. In the "worst-case" limiting case, if BUCKETSIZE is equal to N (all of the entries are in one bucket) we get the same result as obtained in equation (1) for the full search implementation.

As a simplified example of the magnitude by which FASTPNN reduces the number of distance calculations, let's suppose as we did in the last section that we begin PNN with 1000 entries. If we assume that BUCKETSIZE is ten, then only 4,500 distance calculations are required on the first iteration to find the closest vector pairs. This is significantly lower than the 499,500 distance calculations required by the full search implementation on the first iteration.

The number of vectors merged per iteration is given by the term KDMERGE * BUCKETNUM where KDMERGE is a fixed percentage of the top vector pair candidate from each bucket.

Thus, on the second iteration, the number of distance calculations will be reduced to

\[ (\text{N} - \text{KDMERGE} \times \text{N/BUCKETSIZE}) \times (\text{BUCKETSIZE} - 1)/2 \]

Although, the number of distance calculations in determining the candidate vector pairs for merging are greatly reduced by using FASTPNN, there are other computational "overhead" factors associated with the FASTPNN algorithm which are not present in the full search implementation of PNN. From Figure 2, these include initialization of the K-d tree data structure and splitting and merging of buckets. Despite these additional "overhead" factors, it has been shown that FASTPNN has computational efficiency proportional to O(N log N).
3. SOFTWARE/BENCHMARK IMPLEMENTATION OF FASTPNN

As stated in the introduction, the FASTPNN algorithm was delivered to the Government coded in the C programming language. Figure 3 shows a subprogram calling tree of the FASTPNN algorithm. Note from Figure 3, that the FASTPNN subprogram structure divides into 3 main parts. These three parts include BuildKDtree, MergedownKDtree, and DestroyKDtree.

BuildKDtree contains the subroutines which involve building and initialization of the K-d tree data structure. The K-d tree is the data structure which permits the partitioning of the global data set into buckets (localized regions) from which nearest neighbor searches can be performed independently. With reference to Figure 2, the functionality of BuildKDtree is described by block 1 of the block diagram.

MergeDownKDtree contains the routines which reduce the K-d tree built in BuildKDtree to the specified number of centroids (vectors). With reference to Figure 2, the functionality of MergeDownKDtree is described by blocks two through six of the block diagram.

DestroyKDtree contains the routines which permit the deallocation of memory which was dynamically allocated in BuildKDtree and MergeDownKDtree. The functionality of DestroyKDtree is not described in Figure 2, as it is not a necessary part of the FASTPNN algorithm. DestroyKDtree is merely provided to implement the good software practice of deallocating objects no longer in use.

3.1 C Implementation Structure of FASTPNN Benchmark

To permit timing of the C coded FASTPNN algorithm, FASTPNN was integrated with a timer to form a benchmark. The timer measured the process CPU time utilized while running FASTPNN. The basic strategy in timing the FASTPNN algorithm was to have a main (driver) program obtain the initial time just before making a function call to FASTPNN, followed by another call to the timer just prior to executing FASTPNN. The difference between these two times is the time of interest (elapsed time). Because timers use system dependent resources, a separate timer function was written for both the VAX 11/780 and the MIPS MAGNUM 3000. Appendix A provides the C source code listing of the FASTPNN benchmark.

Figure 4 shows the module structure of the C coded FASTPNN benchmark. The FASTPNN benchmark is composed of five modules. Two of the five modules are header files. Header files are used in C to contain definitions and declarations which are to be shared among different files (modules). The arrows in Figure 4 are used to indicate the dependency of particular modules on the header files. For instance, the arrow from FASTPNN.c to FASTPNN.h indicates that FASTPNN.h is to be "included" into FASTPNN.c. Header file Timer.h contains the interface to the system routines which perform the timing of the benchmark. Header file FASTPNN.h contains the data structure declarations which are used in FASTPNN.c and, to a limited extent, in Main.c. The main program, Main.c, is used to read the data, perform the timing of FASTPNN, and output the results.
Figure 3. FASTPNN Subprogram Calling Tree
3.2 Ada Implementation of FASTPNN Benchmark

Presented in this section is the organization structure from a module (or compilation unit) level of the C to Ada translated FASTPNN benchmark. The details of the actual coding from C to Ada are addressed in section 4 of this report. Appendix B provides the source code listing of the Ada coded FASTPNN benchmark.

The Ada coded FASTPNN algorithm was integrated with a timer to form a benchmark. The timer measured the process CPU time utilized while running FASTPNN. As with the case of the C benchmark, a separate timer (body) was written for both the VAX 11/780 and the MIPS MAGNUM 3000.

Figure 5 shows the overall module structure of the Ada coded FASTPNN benchmark. Five packages were used in the benchmark implementation. Data Struct Pkg contains the declarations of all data types used in the benchmark. Packages Build Pkg, MergeDown Pkg, and Destroy Pkg contain all of the FASTPNN subroutines presented in Figure 3. Package Timer Pkg contains the system dependent routines which permit benchmark timing to be performed. The arrows in Figure 5 are used to indicate the dependency of the particular modules with each other. For instance, the arrows pointing from FASTPNN to Build Pkg, MergeDown Pkg, and Destroy Pkg indicates that these three packages must be "withed into" Build Pkg. The main program is used to input the data, time FASTPNN, and output the results.

Figure 6 shows the "package location" of each of the FASTPNN subroutines. Build Pkg contains all of the routines which are nested in the BuildKdtree portion of Figure 3. MergeDown Pkg contains the routines which are nested in the MergeDownKdtree portion of Figure 3. Destroy Pkg contains the routines which are nested in the DestroyKdtree portion of Figure 3. Listed in the Ada specification portion of each of the above three packages, are the routines which must be visible outside of their local package usage. Note from Figure 3, that since FASTPNN calls procedures BuildKdtree, MergeDownKdtree, and DestroyKdtree, these three procedures are all included in the specification (as opposed to body) portion of their respective packages. Procedure CreateKDbucket is included in the specification portion of Build Pkg, since it called by a routine (SplitBucket) outside of Build Pkg. Procedures DestroyKDbucket, DestroyKDnode, DestroyKDentry are included in the specification portion of Destroy Pkg since they are called by routines outside of Destroy Pkg.

3.3 Benchmark Data Set

TASC provided the Government with an input data set to be used for executing the FASTPNN benchmark. The input data set consisted of a single chip of SAR signature prediction data of a B52 aircraft. A chip is a subregion of interest extracted from a larger image (i.e 1K x 1K). Chips typically range in size from 64x64 to 128x128 pixels. An image plot of the B52 aircraft chip is displayed in Figure 7. This data was obtained by using a prediction tool developed at TASC for predicting SAR returns from various targets.
Figure 5. Ada Module Breakdown of FASTPNN Benchmark
Figure 6. Ada Package Implementation of FASTPNN
Figure 7. Image Plot of FASTPNN Input Data Set
The input SAR data set (chip) contained 96x96 samples (vectors). Each sample contained 3 components: an x coordinate position, a y coordinate position, and a gray level (weight). Thresholding was used to reduce the initial data set of 5184 vectors to 1,675 vectors. The purpose of thresholding is to reduce the data set by eliminating vectors with non-significant weight. The reduced set of 1,675 vectors was the actual input to the FASTPNN algorithm.
4. ADA TO C TRANSLATION STRATEGY.

To establish a uniform framework for recoding the FASTPNN benchmark from C to Ada, a C to Ada translation strategy was adopted. Because the goal is to compare the inherent efficiency of Ada with C, no attempt was made in the translation process to improve the execution efficiency of the Ada source code beyond that of the C source code. Thus, a direct "line by line" translation strategy was adopted.

4.1 Data Structures

The first step in the translation process was to "map" the individual C data structures to "equivalent" Ada data structures. In general, the mapping between C and Ada data structures is relatively straightforward. Table 1 below highlights the main data structure mappings used in this study.

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<th>Ada</th>
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<tr>
<td>Pointer Type</td>
<td>Access Type</td>
</tr>
<tr>
<td>Dynamic Array of Pointers (**)</td>
<td>Unconstrained Array of Access Types</td>
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<tr>
<td>Struct</td>
<td>Record</td>
</tr>
<tr>
<td>Union</td>
<td>Record with Variant Part</td>
</tr>
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</table>

Table 2 provides an example of the data structure mapping techniques presented in Table 1 by presenting two of the translated data structures which were extracted from the FASTPNN algorithm. The left hand side of Table 2 shows the original C coded data structure and the right hand side of Table 2 shows the Ada translated data structure. These data structures can be found in Fastpnn.h (Appendix A) and Data_Struct_Pkg (Appendix B) of the C and Ada source code respectively.

The sections below provide a brief explanation of the data structure mappings displayed in Table 1 and used as examples in Table 2.

4.1.1 Dynamic Arrays/Unconstrained Arrays

C Implementation. Structure components *mean, *wmean, and *wsqmn of struct kdentry in Table 2a all correspond to dynamic arrays containing floating point numbers. The number of array components in each of the above arrays is constrained at run time to equal the dimension of the problem's application (i.e. if the problem dimension is two, there would be two components for each array). Thus, in the case of FASTPNN, the use of dynamic arrays permits the flexibility to use FASTPNN for a generalized n dimensional application. At run-time, memory space is dynamically allocated by making a call to the library function calloc with the dimension size passed as a parameter to the function calloc.

Ada Implementation. In Ada, one also could also dynamically allocate the arrays *mean, *weight, and *wsqmn by using allocators. However, Ada
TABLE 2. EXAMPLE OF C TO ADA DATA STRUCTURE MAPPING

<table>
<thead>
<tr>
<th>C</th>
<th>ADA</th>
</tr>
</thead>
<tbody>
<tr>
<td>struct kentry ;</td>
<td>type kentry;</td>
</tr>
<tr>
<td>struct kentry</td>
<td>type kentry_ptr_type is access kentry;</td>
</tr>
<tr>
<td>int</td>
<td>type kentry_ptr_array_type is array (integer range «) of kentry_ptr_type;</td>
</tr>
<tr>
<td>float</td>
<td>type mean_array_type is array (integer range «) of float;</td>
</tr>
<tr>
<td>*next;</td>
<td></td>
</tr>
<tr>
<td>splitleft;</td>
<td></td>
</tr>
<tr>
<td>weight;</td>
<td></td>
</tr>
<tr>
<td>*mean;</td>
<td></td>
</tr>
<tr>
<td>*wmean;</td>
<td></td>
</tr>
<tr>
<td>*wgaqm;</td>
<td></td>
</tr>
<tr>
<td>l;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>ADA</th>
</tr>
</thead>
<tbody>
<tr>
<td>struct knode;</td>
<td></td>
</tr>
<tr>
<td>node</td>
<td></td>
</tr>
<tr>
<td>struct kdbucket;</td>
<td></td>
</tr>
<tr>
<td>bucket</td>
<td></td>
</tr>
<tr>
<td>l norb</td>
<td></td>
</tr>
<tr>
<td>}</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>ADA</th>
</tr>
</thead>
<tbody>
<tr>
<td>struct knode.type</td>
<td>type knode (data_structure) is record</td>
</tr>
<tr>
<td>union</td>
<td></td>
</tr>
<tr>
<td>struct kdbucket.bucket;</td>
<td></td>
</tr>
<tr>
<td>node</td>
<td></td>
</tr>
<tr>
<td>when knode_type = «</td>
<td></td>
</tr>
<tr>
<td>node : knode;</td>
<td></td>
</tr>
<tr>
<td>when kdbucket_type = «</td>
<td></td>
</tr>
<tr>
<td>bucket : kdbucket;</td>
<td></td>
</tr>
<tr>
<td>end case;</td>
<td></td>
</tr>
<tr>
<td>end record;</td>
<td></td>
</tr>
<tr>
<td>norb.n = knode.knode_type;</td>
<td></td>
</tr>
<tr>
<td>norb : knode.kdbucket_type;</td>
<td></td>
</tr>
</tbody>
</table>
permits an easier and more efficient method to derive most of the flexibility of the dynamic array through use of the unconstrained array. The unconstrained array enables one to treat arrays which have the same characteristics but differ only in their size, as equivalent types. Type mean_array_type in Table 2a is an example of an unconstrained array type.

4.1.2 Pointer Types/Access Types

Pointer types in C map to access types in Ada.

4.1.3 Dynamic Array of Pointers/Unconstrained Array of Access Types

C Implementation. Dynamic arrays of pointers were used to maintain linked list pointers in multiple dimensions. As explained in section 4.1.1, the size of the arrays are dynamically allocated to equal the dimension of the application problem. In Table 2a, structure component **next provides an example of a dynamic array of pointers.

Ada Implementation. Unconstrained arr.ys of access types were used to maintain linked list pointers in multiple directions. In Table 2a, record componeent next_array provides an example of an unconstrained array of access types.

4.1.4 Structures/Records

Structures in C map directly to records in Ada.

4.1.5 Structures Containing Unions/Variant Records.

C Implementation. Unions, like structures, contain members whose individual data types may differ from one another. However the members that compose a union all share the same storage area within the computer's memory, whereas each member within a structure is assigned its own unique storage area. Table 2b provides an example of a structure containing a union.

ADA Implementation. Ada does not contain an equivalent data structure directly mapable to the C union isolated (not contained inside another data structure). However, the Ada variant record maps closely to the case where a where a C union is contained within a C structure. In this case, the "union" portion is represented by the variant part of the record. Table 2b provides an example of a variant record.
4.2 C to Ada Coding Dualities

The final step in the C to Ada coding strategy was to highlight the significant coding dualities between C and Ada. Table 3 below outlines a non exhaustive list of coding dualities between C and Ada.

### Table 3. Miscellaneous C to Ada Issues

<table>
<thead>
<tr>
<th>C</th>
<th>Ada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop Statements</td>
<td>Loop Statements</td>
</tr>
<tr>
<td>- for</td>
<td>- for</td>
</tr>
<tr>
<td>- while</td>
<td>- while</td>
</tr>
<tr>
<td>Break</td>
<td>Exit</td>
</tr>
<tr>
<td>Conditional Statements</td>
<td>Conditional Statements</td>
</tr>
<tr>
<td>- if</td>
<td>- if/end if</td>
</tr>
<tr>
<td>- if/else</td>
<td>- if/else/end if</td>
</tr>
<tr>
<td>- if/else if/else if/.../else</td>
<td>- if/elsif/elsif/.../else/end if</td>
</tr>
<tr>
<td>- switch</td>
<td>- case</td>
</tr>
<tr>
<td>Functions</td>
<td>Procedures or Functions</td>
</tr>
<tr>
<td>Pointer Type Operations</td>
<td>Access Types</td>
</tr>
<tr>
<td>- *p</td>
<td>- p.all</td>
</tr>
<tr>
<td>- p-&gt;structure_component</td>
<td>- p.record_component</td>
</tr>
<tr>
<td>- &amp;p</td>
<td>- p'ADDRESS</td>
</tr>
<tr>
<td>Dynamic Allocation</td>
<td>Dynamic Allocation</td>
</tr>
<tr>
<td>- calloc, malloc</td>
<td>- new</td>
</tr>
<tr>
<td>Deallocation</td>
<td>Deallocation</td>
</tr>
<tr>
<td>- Cfree</td>
<td>- Unchecked_Deallocation</td>
</tr>
<tr>
<td>Logical Operators</td>
<td>Logical Operators</td>
</tr>
<tr>
<td>- &amp;&amp;</td>
<td>- and then</td>
</tr>
<tr>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

4.2.1 Loop Statements

Loop statements map very closely between C and Ada and only involve straightforward syntax modifications to convert from one language to the other.

4.2.2 Conditional Statements

Conditional statements map very closely between C and Ada and only involve straightforward syntax modifications to convert from one language to the other.

4.2.3 "Break"/"Exit" Statement
The "break" statement in C and the "exit" statement in Ada permit the innermost enclosing loop to be exited immediately without "testing" at the bottom or top of the loop.

4.2.4 Subprograms

C Implementation. All subprograms in C are implemented as functions. A C function returns a single value as a result of a call.

Ada Implementation. A subprogram in Ada can be implemented either as a function or a procedure. The following guidelines were used to determine whether a function or a procedure was used. A procedure was used whenever two or more parameters were to be modified through a subroutine call. If one or less parameters was to be modified then either a function or a procedure was used. The decision to choose either a function or a procedure was based upon the characteristics of the subprogram. The following coding convention was used when deciding upon a function or a procedure. If the state of the input argument was to be modified then a procedure call was made. Thus, if the subprogram could be written as an Ada "in-out" variable, then an Ada procedure was used. If just some value was returned, then a function was used. Thus, if the variable that needed to change, was characteristic of an Ada "out" parameter, then an Ada function was used.

4.2.5 Pointer Operations

C Implementation. The unary operator * is called the indirection operator. When applied to a pointer, the indirection operator accesses the object that the pointer points to. For example, if a pointer variable, p, points to an integer of value 2, then the statement `x = *p` assigns a value of 2 to the integer variable x. If we assume that the pointer variable, p, points to a structure which contains two members (structure components), say member_1 and member_2 respectively, then the statement `x = p -> member_1` assigns the value of structure component member_1 to the variable x, and the statement `y = p -> member_2` assigns the value of structure component member_2 to variable y. The unary operator &, when applied to a variable, gives the memory address of the object. For example, the statement `p = &x` assigns the address of x to the pointer variable p.

Ada Implementation. The word "all" is used to access objects pointed to by an access type variable. For example, if an access variable type, p, points to an integer of value 2, then the statement `x := p.all` assigns a value of 2 to the integer variable x. If we assume that the access variable, p, points to a record which contains two members, say member_1 and member_2 respectively, then the statement `x := p.member_1` assigns the value of record component member_1 to the variable x and the statement `y := p.member_2` assigns the value of record component member_2 to the variable y. To obtain the memory address of a variable, the attribute 'Address from package system must be used.

4.2.6 Dynamic Allocation

C Implementation. The function calloc was used in conjunction with the function sizeof to obtain blocks of memory dynamically. As an example,
the statement

    ip = calloc(n, sizeof(int))

allocates memory for an array having n elements, with each component having a length equal to number of bytes used by the host machine in representing an integer (usually 2). A pointer ip is returned to these n*2 (assuming an integer is 2 bytes) bytes of uninitialized storage, or NULL if the request cannot be satisfied.

Ada Implementation. Dynamic allocation is performed in conjunction with the "new" statement. Below is the code to translate the same example as presented in the C case above into Ada

    type integer_array_type is array (1 .. n) of integer
    ip := new integer_array_type;

The first statement of the above code declares an array of integers of n elements long of type integer_array_type. The second statement uses the keyword "new" to create a designated object of type integer_array_type and it stores the memory address of the newly created object in access type ip.

4.2.7 Memory Deallocation

Deallocation is used to "free" memory which was previously dynamically allocated but is no longer in use. The storage used by that variable can then be reused to allocate a new variable.

C Implementation. The function free deallocates space which was previously dynamically allocated by a call to calloc or malloc. For example, if we assume that memory was previously dynamically allocated by the statement p = (int *) calloc(n, sizeof(int)) then the statement free(p) frees the space pointed to by p.

ADA Implementation. Unchecked Deallocation is one of the four predefined generic units that are provided by every implementation of the Ada language. In the Ada language, allocated variables are deallocated by calling an instance of the generic procedure Unchecked_Deallocation. A call on an instance of Unchecked_Deallocation takes one variable, which is a variable of access type. The allocated variable designated by the parameter is deallocated, and the parameter is set to NULL. For example, assume that memory was previously dynamically allocated by the statement p := new Integer_Array_Type; where Integer_Array_Type is an array of integers. To deallocate the array of integers, it is first necessary to instantiate the generic procedure Unchecked_Deallocation by the statement "procedure FREE is new Unchecked_Deallocation (Integer, Integer_Array_Ptr_Type);" and then the statement "FREE(Integer_Array_Ptr)" is used deallocate the array. Note, that there is no requirement to use the name "FREE" as any name (i.e. Deallocate_Cell, Dispose, etc) could be used.

4.2.8 Logical Operators.

C Implementation. Logical operators joined by the logical operators
&& and || are evaluated left-to-right, but only until the overall true/false has been established. In the case of the && operator, if the left-hand expression evaluates to false, the AND THEN operator returns the value false immediately without evaluating the right-hand expression. In the case of the || operator, if the left-hand expression is true, the || operator returns a true value without checking the other operand.

ADA Implementation. The Ada equivalents of && and || respectively are AND THEN and OR ELSE respectively. These are called short-circuit AND and short-circuit OR respectively. They produce the same results as the plain AND and OR, but they force the computer to evaluate the expression in left-to-right order.
5. BENCHMARK DEVELOPMENT SYSTEMS

This section provides a description of the two development systems used in this study to perform the benchmarking.

5.1 MIPS MAGNUM 3000.

5.1.1 MIPS MAGNUM 3000 Development System. Below is a description in outline form of the MIPS Magnum 3000 workstation used in this benchmarking study.

- R3000 Central Processing Unit (CPU) running at 25 MHz
- R3010 Floating-Point Coprocessor (FPC), running at 25 MHz
- 32 Kbytes of instruction cache (I-cache) and 32 Kbytes of data cache (D-cache), using 20 ns static RAM (SRAM) with fixed 8-word block-refill size
- ASIC Read/Write Buffer with 8-word buffering
- 16 Mbytes of 100 ns DRAM which supports block-mode transfers with peak data rates of 50 Mbytes per second on writes and 100 Mbytes per second on reads

The R3000 CPU provides 32 general purpose 32-bit registers, a 32-bit Program Counter, and two 32-bit registers that hold the results of integer divide and multiply operations. The R3010 FPC is tightly coupled to the R3000 CPU and can execute instructions in parallel with the CPU. The R3010 contains sixteen, 64-bit registers that can be used to hold single-precision or double-precision values. The MIPS R3000 has 74 instructions while the MIPS R3010 has 20 instructions. However, since eight of the R3000 instructions are common to R3010 instructions, there are a combined total of 86 MIPS instructions. The R3000 can access memory only through simple load/store operations. All MIPS instructions are 32 bits long. Although there is only a single addressing mode (base register plus 16-bit signed displacement), there are numerous individual load and store instructions that can load or store integer data in sizes 8, 16, and 32 bits with signed and unsigned extension.

5.1.2 MIPS Compilers. MIPS compilers support six programming languages including C and Ada. The compiler system has a separate front-end to translate each language and a common back-end to generate optimized machine code. Run-time libraries provide language-dependent functions for each language. The front-ends translate the semantics of each language into an intermediate representation, called U-code. U-code is used by several of the common back-end components.

MIPS uses a common global optimizer, called uopt, for all of their compilers. MIPS categorizes their compiler optimizations into four different levels. Below is a summary of the different optimization levels:

Level 1 - includes peephole and local optimizations
Level 2 - includes level one optimizations, plus the following global optimizations: loop-invariant code motion, strength reduction, common subexpression elimination, and register allocation

Level 3 - includes level two optimizations plus interprocedure register allocation

Level 4 - includes level 3 optimizations, plus procedure inlining

5.1.2.1 MIPS Ada Compiler.

The MIPS Ada compiler provides two global optimizers, namely uopt (discussed in section 5.1.2) and OPTIM3.

OPTIM3 is a high level global optimizer that performs many classical code optimizations and several that are specific to Ada. These include redundant range check elimination and range propagation for elimination of constraint checking.

Version 3.0 of the MIPS Ada compiler was used in this benchmarking study. MIPS Ada 3.0 is intended to support the level 2 optimizations presented in section 5.1.2. However, although the Ada code compiled properly using level 2 optimizations, the run-time execution terminated due to a "segmentation error". Thus, it was necessary to only use level 1 optimizations in compiling the Ada source code.

5.1.2.2 MIPS C Compiler.

The MIPS C compiler used was the 2.11 release. The 2.11 release supports all of the level 4 optimizations presented in section 5.1.2. In this study, the MIPS C code was compiled and executed using level 4 optimizations.

5.2 VAX 11/780.

5.2.1 VAX Hardware.

Below is a description in outline form which summarizes the main features of the VAX 11/780 computer.

- contains a VAX 11/780 processor

- Floating Point Accelerator is optional (used in this study)

- contains an 8 Kbyte cache which hold both data and instructions

- contains as addresss translation buffer (cache) which can hold up to 128 virtual-to-physical page-address translations

- contains an 8 byte instruction buffer
The VAX is the classical example of a Complex Instruction Set Computer (CISC) architecture. There are over 200 different instructions and 7 basic addressing modes. The instruction set operates on integer, floating-point, character-strings and packed-decimal strings, and bit fields. The processor provides 64-bit, 32-bit, 16-bit, and 8-bit arithmetic; instruction prefetch; and an address translation buffer. The CPU includes 16 32-bit general purpose registers for data manipulation and the Processor Status Longword for controlling the execution states of the CPU. The VAX used in this study contained an optional high performance floating point accelerator (FPA). The FPA is an independent processor that executes in parallel with the base CPU. The FPA takes advantage of the CPU's instruction buffer to access main memory. Once the CPU has the required data, the FPA overrides the normal execution flow of the standard floating-point microcode and forces use of its own code. While the FPA is executing the CPU can be performing other operations in parallel.

5.2.2. VAX COMPILERS. This section describes both the VAX Ada compiler and also the VAX C compiler.

5.2.2.1 VAX ADA COMPILER.

Version 1.5 of the VAX ada compiler was used. The compiler was run with full optimization with regard to time. This optimization includes both local and global optimizations similar to those which are performed by the MIPS compilers discussed in section 5.1.2.

5.2.2.2 VAX C Compiler

The VAX C compiler compiler can perform global and local optimization by, for example, doing global flow analysis, assigning automatic variables to register temporaries, and removing invariant computations from loop, to mention a few. The compiler also does peephole optimizations on the generated machine code.

Version 2.3 of the VAX C compiler was used in this study and run with full optimization with regard to time (as opposed to space).
6. BENCHMARK RESULTS/DISCUSSION.

This section presents the benchmark results obtained by running both the Ada and C coded FASTPNN benchmark discussed in section 3 using the coding rules discussed in section 4 on the development systems discussed in section 5.

It is important to reiterate from sections 5.1.2.1 and 5.1.2.2, that the MIPS C code was compiled and executed using level 4 compiler optimizations while the MIPS Ada code was compiled with level 1 optimizations. Recall, that this is due to the fact that MIPS level 3 and 4 compiler optimizations were not supported in the Ada compiler used (Version 3.0). Further, when the Ada code was executed using level 2 optimizations a fatal segmentation error resulted. Thus, only level 1 optimizations could be used for the Ada.

In an attempt to circumvent the discrepancies between the MIPS C compiler optimizations and the MIPS Ada optimizations, in section 6.2, projections of Ada execution time are made based upon level 4 compiler assumptions. The motivation for such a discussion is that eventually level 4 optimizations will be incorporated in Ada. The level 4 Ada execution time projections are based upon using the scaling factor associated with the C execution improvement when going from level 1 to level 4 optimizations. Thus, the level 4 Ada execution time projections are obtained by multiplying the Ada level 1 execution time by the C level 4 execution time, and then dividing this result by the C level 1 execution time.

6.1 Ada Without Checks Versus Ada With Checks

To support the use of exceptions, Ada performs run time checks to determine whether an exception should be raised. In practice, a clever compiler can determine that many of the checks can be safely omitted. Nevertheless, a compiler may continue to generate checks that a programmer knows are unnecessary, and these checks may make a critical difference in the execution time of a program. The different run time checks include access checks, discriminant checks, index checks, length checks, range checks, division checks, and overflow checks.

To investigate the execution time overhead in performing checks, the FASTPNN Ada code was executed for both the case where Ada checks were performed and also the case where all Ada checks were suppressed (no checks).

Figure 8 contrasts the execution efficiency of the Ada code run for the case where Ada run-time checking was performed versus the case where run-time checking was suppressed. Figure 8 indicates that Ada run-time checks imposes a significant penalty on the execution efficiency of the Ada for both the VAX and the MIPS. On the VAX, the PNN execution time goes from approximately 25 seconds with checks off to approximately 36 seconds with checks on. This corresponds to a 43% increase in time for performing checks on the VAX. On the MIPS, the execution time goes from approximately 2.4 seconds with checks suppressed to 4 seconds with checks preformed. This corresponds to a 65% increase in time for performing checks on the MIPS. Thus, the relative penalty for performing Ada run-time checks is moderately higher for the MIPS than for the VAX.
FIGURE 8. EFFECT OF ADA RUN TIME CHECKS ON EXECUTION EFFICIENCY

<table>
<thead>
<tr>
<th></th>
<th>MIPS MAGNUM 3000</th>
<th>VAX 11/780</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ada (no checks)</td>
<td>2.43</td>
<td>25.11</td>
</tr>
<tr>
<td>Ada (checks)</td>
<td>4</td>
<td>35.96</td>
</tr>
</tbody>
</table>

(Secs)
6.2 C Versus Ada

Figure 9 contrasts the execution efficiency of the C code with the Ada code. The relative efficiency of C versus Ada depends on which machine the code is executed on. If the code is executed on the VAX, than the Ada executes more efficiently than the C. For the case of the VAX, the Ada executes approximately 39.5% quicker than the C when Ada checks are suppressed and 13.3% quicker than the C when Ada checks are performed. On the other hand, if the code is executed on the MIPS the C code runs quicker than the Ada code. For the MIPS, the C code runs approximately 40% quicker than the Ada code when Ada checks are suppressed and 114% quicker than the Ada code when Ada checks are incorporated.

Figure 10 contrasts the execution efficiency of Ada versus C for the case where level 4 Ada compiler optimizations are projected using the scaling technique discussed in section 6. Note from Figure 10 that the Ada execution time for the case where Ada checks are not incorporated is nearly identical to the C execution time.

Based on Figures 9 and 10 it is concluded that there is little or no difference between the inherit execution efficiency of Ada (without checks) and that of C. The actual execution efficiency of Ada versus C is driven by the maturity of the compilers used in the comparison. With regard to the MIPS, the fact that the C code runs quicker than the Ada is attributed to the fact that the present MIPS Ada compiler is not as mature as the MIPS C compiler. This is because the MIPS Ada compiler was run with level 1 compiler optimizations while the MIPS C compiler was run using level 4 compiler optimizations. Figure 10 indicates that eventually when the MIPS Ada compiler matures to the level of the C compiler, the Ada code will execute in nearly identical efficiency (time) as the C code.

The fact that the Ada code on the VAX executes more efficiently than the C code on the VAX is attributed to the hypothesis (this was not proven in this study) that the VAX is less efficient than the MIPS in performing dynamic allocation. Thus, in the case of Ada, where the unstrained array was used in replacement to performing dynamic array allocation using access types, the resulting Ada code was more efficient than the C code where dynamic allocation had to be performed. On the MIPS, however, where dynamic allocation is performed more efficiently this difference between Ada and C was nullified.

6.3 MIPS Versus VAX

By far the most common method used to gauge the performance of a particular machine is to measure its performance relative to the VAX 11/780. A ratio, expressed in terms of VAX MIPS, is obtained by dividing the time required to execute a given benchmark on the VAX versus the time to execute that same benchmark on a different computer. This ratio is used to express the machine's performance relative to the VAX; the higher the ratio, the better the machine's performance. Figure 11 contrasts the execution efficiency of the MIPS MAGNUM 3000 with the VAX 11/780. Note from Figure 11 that the ratio of MIPS execution time versus VAX execution time is highly dependent on whether Ada or C is used. If C is the language, then the ratio is approximately 22.2 VAX MIPS. If Ada is the language the MIPS ratio
Figure 9. FASTPNN EXECUTION TIME COMPARISON

Note: MIPS C used Level 4 optimizations. MIPS Ada used Level 1 optimizations.

MIPS MAGNUM 3000

- C
- Ada (no checks)
- Ada (checks)

VAX 11/780

- 1.87
- 2.43
- 4
- 41.48
- 25.11
- 35.96
FIGURE 10. FASTPNN EXECUTION TIME COMPARISON BASED UPON ADA LEVEL 4 OPTIMIZATION PROJECTIONS

(Seconds)

<table>
<thead>
<tr>
<th>Level 1 Optimiz</th>
<th>Level 4 Optimiz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.46</td>
<td>1.87</td>
</tr>
<tr>
<td>2.43</td>
<td>1.86</td>
</tr>
</tbody>
</table>

Projected: 3.06

- C
- Ada (no checks)
- Ada (with checks)
drops off dramatically and is dependent, to a small degree, on whether Ada is run with run-time checks or without run-time checks. If Ada is run without checks than the ratio is approximately 10.3 VAX MIPS. In the case where Ada is run using run-time checks, the ratio reduces to approximately 9.0 VAX MIPS.

The above results indicate that the MIPS MAGNUM 3000 is somewhere between 9 to 22.2 times faster than the VAX 11/780, with the variance in ratio attributed to the compiler. Since C compilers are more mature than Ada compilers, it is concluded that the C run time results are a better indicator of inherit machine performance than the Ada run time results. Thus, it is concluded that the actual speedup of the MIPS over the VAX is reflected most accurately by the C VAX ratio of 22.2 VAX MIPS.

6.4 MIPS Profiler Results

The purpose in profiling is to help identify the areas of code where most of the execution time is spent. In the typical program, execution time is disproportionately spent in relatively few sections of code. Having identified these critical sections of code, it is profitable to improve coding efficiency in those sections.

The results presented in this section were obtained by using the MIPS UNIX profiler. In both the C and Ada case, the profiler output statistics assume 100% cache hits. For each subroutine in PNN, the profiler outputs the following statistics: the total number of cycles used by that routine (CYCLES), the percentage of cycles the routine uses with respect to the total number of program cycles (%CYCLES), the cumulative percentage of cycles (CUM%), the total number of times each routine is called, and the number of cycles used by the routine per call (CYCLES/CALL). Note that there is a direct relation between cycles used and execution time; simply divide the cycles used by the clock frequency (25 MHz) to get the actual time.

Since the profiler results presented in this section are categorized by subroutine, a brief description of the seven most time consuming subroutines contained in FASTPNN are presented in Table 4. Table 4 can be used to gain insight into the time breakdown of the FASTPNN routines in terms of computational functionality.

6.4.1 C Profiler Results

In this section the profiler was run on the FASTPNN C code using level 2 compiler optimizations. Table 5 summarizes the profiler results for the seven most time consuming subroutines in FASTPNN. Table 5 lists the seven routines in descending order corresponding to their overall contribution with regard to cycles used in the execution of FASTPNN. Note from Table 5 that the seven routines account for approximately 89% of the total cycles used in the entire FASTPNN algorithm. The routine which accounts for the greatest percentage of cycles (time) is GetBucketStats. From Table 4 one can see that GetBucketStats is concentrated on basic floating point mathematics in performing mean and variance calculations. The first four of the routines listed in Table 5 account for over 80% of the total cycles used. Also note from Table 5 that routine Indxx is by far the most time-
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>SUBROUTINE DESCRIPTION</th>
<th>FUNCTIONS TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AssessCandidate</td>
<td>Determine distortion among all pairs of bucket entries</td>
<td>floating point arithmetic, conditional branching, linked list traversal</td>
</tr>
<tr>
<td>CollapseKDnode</td>
<td>recursive routine used to collapse entries in a Kd tree into a single bucket</td>
<td>linked list manipulation, conditional branching, recursive calling</td>
</tr>
<tr>
<td>GetBucketStats</td>
<td>mean and variance calculation for each bucket</td>
<td>floating point arithmetic, array manipulation, linked list traversal</td>
</tr>
<tr>
<td>Indexx</td>
<td>heapsort on vector position coordinates</td>
<td>array indexing, conditional branching</td>
</tr>
<tr>
<td>Qsort</td>
<td>sort candidate pairs of entries from each bucket for merging</td>
<td>recursive calling, conditional branching</td>
</tr>
<tr>
<td>ReduceKDbucket</td>
<td>merge a pair of entries into a single entry</td>
<td>floating point arithmetic, linked list manipulation</td>
</tr>
<tr>
<td>SplitBucket</td>
<td>recursive routine used to split a K-d tree bucket into two buckets having half as many entries</td>
<td>linked list manipulation, recursive calling, conditional branching</td>
</tr>
</tbody>
</table>
### TABLE 5. MIPS C PROFILER RESULTS

<table>
<thead>
<tr>
<th>SUBROUTINE</th>
<th>CYCLES</th>
<th>%CYCLES</th>
<th>CUM%</th>
<th>CALLS</th>
<th>CYCLES/CALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>GetBucketStats</td>
<td>11,151,089</td>
<td>25.76</td>
<td>25.76</td>
<td>3277</td>
<td>3403</td>
</tr>
<tr>
<td>SplitBucket</td>
<td>9,495,506</td>
<td>21.94</td>
<td>47.70</td>
<td>6617</td>
<td>1435</td>
</tr>
<tr>
<td>CollapseKNode</td>
<td>8,483,026</td>
<td>19.60</td>
<td>67.30</td>
<td>3277</td>
<td>2589</td>
</tr>
<tr>
<td>AssessCandidate</td>
<td>5,735,734</td>
<td>13.25</td>
<td>80.55</td>
<td>3343</td>
<td>3343</td>
</tr>
<tr>
<td>Indxx</td>
<td>1,944,679</td>
<td>4.49</td>
<td>85.04</td>
<td>2</td>
<td>972,340</td>
</tr>
<tr>
<td>qsort</td>
<td>962,354</td>
<td>2.22</td>
<td>87.26</td>
<td>4498</td>
<td>214</td>
</tr>
<tr>
<td>ReduceKDbucket</td>
<td>935,071</td>
<td>2.16</td>
<td>89.42</td>
<td>1671</td>
<td>560</td>
</tr>
</tbody>
</table>
consuming routine with regard to the number of cycles required on a per call basis, requiring over 970,000 cycles per call. But because Indxx is only called twice, it accounts for just approximately 4.5% of the total cycles used.

6.4.2 Ada Profiler Results

In this section the profiler was run on the Ada code using level 1 compiler optimizations and suppressing all Ada run time checks. Table 6 summarizes the profiler results for the seven most significant subroutines in FASTPNN. Table 6 lists the seven routines in descending order corresponding to their overall contribution with regard to cycles used in the execution of FASTPNN. Note from Table 6 that the seven routines account for approximately 94% of the total cycles used in the entire PNN algorithm. The routine which accounts for the greatest percentage of cycles (time) is SplitBucket. From Table 4 one can see that SplitBucket is computationally intensive in the areas of recursive calling, linked list manipulation, and conditional branching. The first four of the routines listed in Table 6 accounts for over 84% of the total cycles used in FASTPNN. Also note from Table 6 that routine Indxx is by far the most time consuming routine on a per call basis requiring approximately 1.3 million cycles per call.

6.4.3 Ada Versus C Profiler Results

Table 7 contrasts the performance of the Ada profiler results with the C profiler results for each of the main routines listed in the previous two sections. The seven routines are presented in alphabetical order in Table 7. Table 7 displays the amount of cycles used by each routine, the relative percentage of cycles that the routine contributes to the entire FASTPNN cycle count, and a ranking of each routine corresponding to its relative contribution of cycles used. With the exception of routine AssessCandidate, the results displayed in Table 7 are consistent from the standpoint that the Ada routines use more cycles than the C routines. In the case of AssessCandidate, the C requires more cycles than the Ada. With the exception of routines SplitBucket and GetBucketStats, the relative ranking of the individual routines for C versus Ada is also consistent. In the case of routine SplitBucket, SplitBucket is the most time consuming routine (rank 1) in the case of Ada while, in the case of C, SplitBucket is the second most time consuming routine (rank 2). In the case of routine GetBucketStats, GetBucketStats is the second most time consuming routine (rank 2) in the case of Ada, while GetBucketStats is the most time consuming routine (rank 1) in the case of C.

The last row of Table 7 shows the total cycles from the seven routines combined and the cumulative percentage of cycles this sum comprises of the overall cycles used in the FASTPNN execution. Note, that the total cycles used by the Ada exceeds the total cycles used by the C code. This result is consistent with the execution results previously displayed in Figure 9.
### Table 6. MIPS ADA PROFILER RESULTS

<table>
<thead>
<tr>
<th>SUBROUTINE</th>
<th>CYCLES</th>
<th>CALLS</th>
<th>CYCLES/CALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SplitBucket</td>
<td>15,143,120</td>
<td>6628</td>
<td>2285</td>
</tr>
<tr>
<td>GetBucketStats</td>
<td>14,259,413</td>
<td>3281</td>
<td>4347</td>
</tr>
<tr>
<td>CollapseKNode</td>
<td>8,936,579</td>
<td>3281</td>
<td>2724</td>
</tr>
<tr>
<td>AssessCandidate</td>
<td>4,977,050</td>
<td>3347</td>
<td>1488</td>
</tr>
<tr>
<td>Indxx</td>
<td>2,540,485</td>
<td>2</td>
<td>1,270,243</td>
</tr>
<tr>
<td>QuickSort</td>
<td>1,618,782</td>
<td>238</td>
<td>338</td>
</tr>
<tr>
<td>ReduceKDbucket</td>
<td>1,164,919</td>
<td>697</td>
<td>489</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUBROUTINE</th>
<th>%CYCLES</th>
<th>CUM%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SplitBucket</td>
<td>29.46</td>
<td>100</td>
</tr>
<tr>
<td>GetBucketStats</td>
<td>27.75</td>
<td>51.71</td>
</tr>
<tr>
<td>CollapseKNode</td>
<td>17.38</td>
<td>69.09</td>
</tr>
<tr>
<td>AssessCandidate</td>
<td>9.68</td>
<td>78.77</td>
</tr>
<tr>
<td>Indxx</td>
<td>4.94</td>
<td>83.71</td>
</tr>
<tr>
<td>QuickSort</td>
<td>2.95</td>
<td>86.66</td>
</tr>
<tr>
<td>ReduceKDbucket</td>
<td>2.27</td>
<td>88.93</td>
</tr>
</tbody>
</table>
### TABLE 7. COMPARISON OF MIPS PROFILER RESULTS (ADA VERSUS C)

<table>
<thead>
<tr>
<th>SUBROUTINE</th>
<th>ADA CYCLES</th>
<th>ADA %CYCLES</th>
<th>ADA RANK</th>
<th>C CYCLES</th>
<th>C %CYCLES</th>
<th>C RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>AssessCandidate</td>
<td>4,977,050</td>
<td>9.68</td>
<td>4</td>
<td>5,735,734</td>
<td>13.25</td>
<td>4</td>
</tr>
<tr>
<td>CollapseKDnode</td>
<td>8,936,579</td>
<td>17.38</td>
<td>3</td>
<td>8,483,026</td>
<td>19.60</td>
<td>3</td>
</tr>
<tr>
<td>GetBucketStats</td>
<td>14,259,413</td>
<td>27.75</td>
<td>2</td>
<td>11,151,089</td>
<td>25.76</td>
<td>1</td>
</tr>
<tr>
<td>Indxx</td>
<td>2,540,485</td>
<td>4.94</td>
<td>5</td>
<td>1,944,679</td>
<td>4.49</td>
<td>5</td>
</tr>
<tr>
<td>QuickSort</td>
<td>1,518,782</td>
<td>2.95</td>
<td>6</td>
<td>962,354</td>
<td>2.22</td>
<td>6</td>
</tr>
<tr>
<td>ReduceKDbucket</td>
<td>1,164,919</td>
<td>2.27</td>
<td>7</td>
<td>935,071</td>
<td>2.16</td>
<td>7</td>
</tr>
<tr>
<td>SplitBucket</td>
<td>15,143,120</td>
<td>29.46</td>
<td>1</td>
<td>9,495,506</td>
<td>21.94</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>48,540,348</td>
<td>94.43</td>
<td></td>
<td>38,707,459</td>
<td>89.42</td>
<td></td>
</tr>
</tbody>
</table>
7.0 PROJECTED FASTPNN REAL-TIME REQUIREMENT

The goal of this section is to motivate a FASTPNN real time requirement. The basic strategy used in motivating the FASTPNN real time requirement derived in this section is outlined below:

A. First, determine the MBV real time requirement/goal (how many targets need to be recognized in how many seconds?)

B. Next, determine what percentage of time an MBV system will be spend on FASTPNN

C. Last, multiply the percentage of time spent on FASTPNN (B above) by the overall MBV real-time requirement (A above). FASTPNN must then be able to complete its execution in this derived interval of time

There is currently a program sponsored by the Air Force called Automatic Radar Air-to-Ground Acquisition Program (ARAGTAP) which is focused on establishing a real-time MBV capability. The ARAGTAP goal is to identify 20 to 40 objects (targets) from a high resolution SAR image in approximately 7 seconds. If we conservatively assume a 20 to 30% alarm rate, this requirement translates to identifying approximately 50 chips (of which 20 to 40 may be actual targets) that range in size from 64 x 64 pixels to 128 x 128 pixels in 7 seconds.

Step B in our strategy to determine a FASTPNN real-time requirement is to determine the relative percentage of the time that the MBV algorithm will spend on FASTPNN. A heuristic reasoning process was used to estimate that FASTPNN should account for approximately 1.86% of the total MBV processing time. The heuristic reasoning process included the following assumptions:

- 10% of MBV should be spent on prescreening/detection and the other 90% should be spent on recognition

- of the remaining 90% of the time spent on recognition, 25% of the processing time should be spent on information extraction algorithms and 75% should be spent on classification/matching algorithms

- of the 25% of the time spent on information extraction, 8.25% of this time should be spent on the FASTPNN algorithm.

Mathematically combining all of the above assumptions (by multiplying), it is found that the FASTPNN algorithm accounts for approximately 1.86% of the total MBV execution time.

Since we are assuming that 50 chips must be processed in 7 seconds, it is determined that the FASTPNN algorithm must be able to process a single chip (as was done in this study) in .0026 seconds.

In section 6 the best case FASTPNN execution time was 1.87 seconds; this is nearly 3 orders of magnitude slower than the FASTPNN real-time requirement previously derived in this section.
8.0 FASTPNN/PNN IMPLEMENTATION CONSIDERATIONS

Based upon the discussion in section 7, it is evident that FASTPNN execution efficiency must be greatly increased if it is to function within real-time MBV constraints.

In section 2.1 it was shown that FASTPNN had computational requirements that are $O(N \log N)$ while the full search PNN had computational requirements $O(N^2)$. The fact that the full search algorithm is $O(N^2)$ and that FASTPNN is $O(N \log N)$ does not necessarily imply that FASTPNN will execute more quickly than full search PNN over all input data sets. In fact, for up to relatively large data set sizes, $N$, it is highly conceivable that the full search implementation PNN will execute more efficiently than FASTPNN. This is attributed to the fact that there are initializations and other overhead associated with the FASTPNN algorithm. However, as $N$ gets very large, the volume of calculations associated with the full search implementation will dominate all overhead associated with FASTPNN, and the full search implementation will run slower than FASTPNN. A logical question to ask is: "for a given data set size which implementation of PNN should one use?" For the sake of convenience we will designate the parameter BREAK EVEN $N$ to refer to the data set size, $N$, where the execution time of FASTPNN and full search PNN would be equal. It will be understood that for $N < \text{BREAK EVEN } N$, the full search implementation will run quicker than FASTPNN, and for $N$ greater than BREAK EVEN $N$, the full search implementation will run slower than FASTPNN.

It is important to emphasize that BREAK EVEN $N$ does not indicate the data set size where both implementations of PNN are equally as good. Given equal execution time for both implementations of PNN, the full search implementation of PNN is superior to FASTPNN since the resulting quantization vectors are optimum. In fact, it is logical to assume that significant computational savings must be obtained to warrant the use of FASTPNN over the full search implementation.

One strong disadvantage of the full search PNN is the large memory requirement which would be required if a large input data set size is used. For example, it was shown by example in section 2.1 that if the input data set contains 1000 entries, then 499,500 distance calculations would be required to be computed in the first iteration. If each distance calculated were to be stored in one word, then this requirement translates to nearly two megabytes of memory.

Intuitively, the parameter BREAK EVEN $N$ is dependent on the actual architecture used in executing the PNN algorithm. In this study, where benchmarking was performed on general purpose data processors it was assumed (but not demonstrated) that, for the given input data set, FASTPNN was more time efficient than full search PNN. However, if one were to consider executing the PNN algorithm on a signal processor (as opposed to a data processor), the choice between choosing the full search implementation of PNN versus FASTPNN could certainly be altered. A signal processor will be defined, in the context of this section, as a processor specifically designed to perform sequences of computations/operations unaffected by actual data values. Since a signal processor is more suited to do the brute force, less decision intensive,
calculations required by the full search PNN compared to the more data
dependent calculations of FASTPNN, than it is logical to conclude that
the full search PNN will exhibit higher execution efficiency over a
larger range of input data size.

Figure 12 is used to illustrate the points made in the above paragraphs.
Figure 12 shows four hypothetical curves which are used to contrast the
execution efficiency of FASTPNN versus full Search PNN for both a data
and signal processor as a function of input data set size, N. The four
curves include: (1) the execution time of FASTPNN on a signal processor
as a function of N; (2) the execution time of FASTPNN on a data
processor as a function of N; (3) the execution of FASTPNN on a signal
processor as a function of N, and (4) the execution of full search PNN
on a signal processor as a function of N. Figure 10 shows that for
small values of N, for both the signal and data processor
implementation, the full search implementation of PNN is more efficient
than FASTPNN. But, for both the data and signal processor alike, as N
gets large, FASTPNN eventually exhibits higher execution efficiency than
the full search implementation of PNN. Note from Figure 12 that
BREAK EVEN N for the data processor occurs for a much smaller input data
size, than for the signal processor. Also note from Figure 12,
that the data processor displays slightly better execution efficiency
than the signal processor for all values of N in executing FASTPNN. But
in executing the full search implementation of PNN, the signal processor
significantly outperforms the data processor for all values of N.
FIGURE 12. HYPOTHETICAL EFFICIENCY COMPARISON OF DATA PROCESSOR VERSUS SIGNAL PROCESSOR

LOG OF HYPOTHETICAL EXECUTION TIME

DP (FULL SEARCH)

BREAK EVEN N

SP (FULL SEARCH)

SP = SIGNAL PROCESSOR
DP = DATA PROCESSOR
9. CONCLUSIONS

9.1 Ada With Checks Versus Ada Without Checks

Ada run-time checks impose a significant penalty on Ada execution efficiency for both the MIPS and the VAX. On the VAX there was a 43% relative time "penalty" (increase in time) associated with performing run-time checks, while on the MIPS, there was a 65% time penalty associated with performing run-time checks.

9.2 C Versus Ada

There is no inherent execution efficiency advantage of C over Ada or vice versa. The comparison of C versus Ada depends on the relative maturity of the compilers used. For instance, on the MIPS Magnum 3000, the C code executes more efficiently than the Ada code. While on the VAX, the Ada code executes more efficiently than the C code. Thus, the resulting conclusion is that for the MIPS Magnum 3000, the C compiler is more mature than the Ada compiler, while for the VAX 11/780 the Ada compiler is more mature than the C compiler.

9.3 MIPS Magnum 3000 Versus VAX 11/780

Depending on the language used in the comparison, the MIPS Magnum 3000 executed between 9 and 22 times more efficiently (9 to 22 times less time) than the VAX 11/780. When Ada was the language compared on both machines, the MIPS executed 9 times faster than the VAX. When C was the language, the MIPS executes 22 times faster than the VAX. The discrepancy between C and Ada indicate that the relative efficiency of MIPS C over VAX C is larger than the efficiency of MIPS Ada over VAX Ada.

9.4 FASTPNN/ Real-Time Implementation Considerations

The best case FASTPNN execution time obtained from executing the C coded algorithm on the MIPS Magnum 3000 is estimated to be approximately 3 orders of magnitude too slow for real time use. Specialized signal processor hardware will be required to boost the execution efficiency of FASTPNN to real time performance levels. When using specialized signal processor hardware, it may be advantageous to implement the full search PNN algorithm. The brute force, less decision intensive calculations required by the full search PNN algorithm make it more suitable for signal processor hardware application than the FASTPNN algorithm. Since the choice of algorithm implementation is dependent on the input data set size, a study should be performed to determine which implementation is best for a given input data set size. Given equal execution times for both the full search PNN implementation and the FASTPNN implementation, the full search implementation is preferred since it provides the more accurate results.
REFERENCES


APPENDIX A

C CODED FASTPNN BENCHMARK SOURCE CODE
<table>
<thead>
<tr>
<th>ROUTINE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN</td>
<td>A-2</td>
</tr>
<tr>
<td>FASTPNN HEADER FILE</td>
<td>A-4</td>
</tr>
<tr>
<td>FASTPNN</td>
<td>A-6</td>
</tr>
<tr>
<td>VAX TIMER HEADER FILE</td>
<td>A-35</td>
</tr>
<tr>
<td>VAX TIMER</td>
<td>A-36</td>
</tr>
<tr>
<td>MIPS TIMER HEADER FILE</td>
<td>A-37</td>
</tr>
<tr>
<td>MIPS TIMER</td>
<td>A-38</td>
</tr>
<tr>
<td>SAMPLE OF DATA INPUT FILE</td>
<td>A-39</td>
</tr>
</tbody>
</table>
#include "timer.h"
#include "fastpnn.h"
#include <stdio.h>

float *FastPNN (float *means, float *weights, int count, 
    int dim, int ncntrds);

Main(int argc, char *argv[]) 
/

    float *results;
    float *positions;
    float *weights;
    float a, b, c;
    int count;
    int dim;

    int ncntrds, i, j, k;

    int loop_count = 1;
    int initial_dummy_time, dummy_arg, dummy_elapsed_time;
    int init_fastpnn_time, fastpnn_elapsed_time;
    float fastpnn_iteration_time;
    int vector_count;
    int weight_count;
    int position_count;

    FILE *fpt_in;
    FILE *fpt_out;

    i = 0;
    j = 0;

    fpt_in = fopen(argv[1], "r");
    fpt_out = fopen(argv[2], "w");
    vector_count = atoi(argv[3], "r");
    position_count = 2 * vector_count;
    ncntrds = 4;

    positions = (float *)calloc(position_count, sizeof(float));
    weights = (float *)calloc(vector_count, sizeof(float));

    while (feof(fpt_in) == 0) {

A-2
fscanf (fpt_in, "%f %f %f", &a, &b, &c);
positions[i++] = a;
positions[i++] = b;
weights[j++] = c;
}

count = vector_count;
dim = position_count/vector_count;
printf("enter fastpnn\n");

initial dummy time = init_timer();
printf("got initial dummy time\n");
for (i=0; i<loop_count; i++)
{
    dummy_arg = identity(dummy_arg);
}
dummy elapsed time = elapsed time(initial dummy time);
printf("dummy elapsed time = %d", dummy_elapsed_time);

init fastpnn time = init_timer();
for (i=0; i<loop_count; i++)
{
    results = FastPNN(positions, weights, count, dim, ncntrds);
    dummy_arg = identity(dummy_arg);
}
fastpnn_elapsed_time = elapsed time(init fastpnn_time);

fastpnn_iteration_time = (fastpnn_elapsed_time - dummy_elapsed_time) / loop_count;

fprintf(fpt_out, "Fastpnn executed in %f", fastpnn_iteration_time);
fprintf(fpt_out, "microseconds\n");
fprintf(fpt_out, "Returned results\n");
printarray(results, dim, ncntrds);
fclose(fpt_out);

int printarray(float *array, int dim, int count)
{
    int i, j, k;

    for (i=0, k=0; i != count; i++) {
        printf(" (");
        for (j=0; j != dim; j++, k++) {
            printf("%f", array[k]);
            if (j != dim - 1)
                printf(" ");
            else
                printf(")\n");
        }
    }
}
/* This is the header file, "Fastpnn.h", which contains the
 * data structure definitions, function prototype definitions, and
 * symbolic name definitions for the FastPNN C program */

#ifndef FastPNN
#define _FastPNN_
#endif

#ifndef TRUE
#define TRUE -1
#endif

#ifndef FALSE
#define FALSE 0
#endif

#define KDNODE 0
#define KDBUCKET 1

#define KDMEMERR "KD tree memory allocation error\n"

#define BUCKETSIZE 8 /* Number of entries per bucket */
#define KDMERGE 0.5 /* Fraction of buckets merged */

#define APTR (char *)

struct kdentry {
    struct kdentry **next; /* k dimensional linked list pointers */
    int splitleft; /* flag used for bucket splitting */
    float weight; /* Weight assigned to this entry */
    float *vmean; /* k dimensional weighted sample data */
    float *wsqmn; /* k dim. weighted square sample data */
};

struct knode {
    int dindx; /* Dimension index */
    struct kdelem *lower; /* Pointer to kdelems below thresh */
    struct kdelem *upper; /* Pointer to kdelems above thresh */
};

struct kdbucket {
    int count; /* Cardinality of bucket entries */
    struct kdentry **lists; /* Pointers to sorted data linked list */
    struct kdentry *entrya; /* First element of candidate pair */
    struct kdentry *entryb; /* Second element of candidate pair */
    float distort; /* Distortion induced by merging pair */
};

struct kdelem {
    int type; /* value of KDNODE or KDBUCKET */
    union {
        struct knode node; /* node or bucket union */
        struct kdbucket bucket;
    } norb;
};
struct kdtree {
  int dim;        /* Dimension of tree entries */
  struct kdelem *root;  /* Pointer to first kd tree element */
  int nbuckets;    /* Number of terminal nodes */
  int nentries;    /* Total number of sample points */
};

#endif

void fatal_message(char string[]);
#include "fastpnn.h"

float *FastPNN (means, weights, count, dim, ncntrds)

float *means, *weights;
int count, dim, ncntrds;

/*
 * Function name:
 *   FastPNN
 *
 * Purpose:
 *   Main routine for the Pairwise Nearest Neighbor clustering algorithm
 *
 * Input arguments:
 *   means - sample point array
 *   weights - sample weight array
 *   count - number of samples
 *   dim - dimensionality of the sample data
 *   ncntrds - target number of clusters to form from the data
 *
 * Output arguments:
 *   None
 *
 * Returns:
 *   STACK - array of clusters
 */

{
    struct kdentry *entry;
    struct kdtree *tree, *BuildKDtree();
    float *centroids;
    void MergeDownKDtreet(), DestroyKDtreet();
    /* char *calloc(); */
    int i, j, k;

    if (!(centroids = (float *)calloc((unsigned)ncntrds*dim,sizeof(float))))
        fatal_message(KDMEMERR);

    tree = BuildKDtree(means,weights,count,dim);

    MergeDownKDtreetree, ncntrds);

    entry = tree->root->norb.bucket.lists[0];
    for (i=0,k=0; i!=ncntrds; i++,entry=entry->next[0])
        for (j=0; j!=dim; j++,k++)
            centroids[k] = entry->mean[j];

    DestroyKDtree(tree);

    return(centroids);
}
#include "fastpnn.h"

struct kdtree *BuildKDtree(means,weights,count,dim)
{
    float *means, *weights;
    int    count, dim;

    /*
     * Function name:
     *   BuildKDtree
     * 
     * Purpose:
     *   Constructs an initial kD tree from the sample data
     *
     * Input arguments:
     *   means   - sample point array
     *   weights - sample weight array
     *   count   - number of samples
     *   dim     - dimensionality of the sample data
     *
     * Output arguments:
     *   None
     *
     * Returns:
     *   STACK    - pointer to a kD tree
     */

    struct kdtree *tree, *CreateKDtree();
    struct kdelem *CreateFirstBucket();

    tree     = CreateKDtree(dim);
    tree->root = CreateFirstBucket(means,weights,count,dim);
    tree->nbuckets = 1;
    tree->nentries = count;

    return(tree);
}


#include "fastpnn.h"

struct kdtree *CreateKDtree(dim)

    int dim;

/*
 * Function name:
 *    CreateKDtree
 *
 * Purpose:
 *    Allocates storage for a kD tree data structure
 *
 * Input arguments:
 *    dim    - dimensionality of the tree data
 *
 * Output arguments:
 *    None
 *
 * Returns:
 *    STACK    - pointer to a kD tree
 */

( struct kdtree *tree;

if (!tree = (struct kdtree *)calloc((unsigned)1,sizeof(struct kdtree)))
    fatal_message(KDMEMERR);

    tree->dim = dim;

    return(tree);
)
#include "fastpnn.h"

void DestroyKDtree(tree)
    struct kdtree *tree;

    /*
    * Function name:
    *    DestroyKDtree
    *
    * Purpose:
    *    Destroy a kD tree
    *
    * Input arguments:
    *    tree    - pointer to the kD tree
    *
    * Output arguments:
    *    None
    *
    * Returns:
    *    Nothing
    */

    { void DestroyLastBucket();

        if (tree->root)
            DestroyLastBucket(tree->root);
        DestroyLastBucket(tree->root);
        cfree((char *)tree);
    }
#include "fastpnn.h"

struct kdelem *CreateFirstBucket (means, weights, count, dim)

    float *means, *weights;
    int count, dim;

/**
 * Function name:
 *     CreateFirstBucket
 *
 * Purpose:
 *     Create and initialize the first bucket in a kD tree
 *
 * Input arguments:
 *     means   - sample point array
 *     weights - sample weight array
 *     count   - number of samples
 *     dim     - dimensionality of the sample data
 *
 * Output arguments:
 *     None
 *
 * Returns:
 *     STACK    - Initialized bucket
 */

{
 struct kdelem *bucket, *CreateKDbucket();
 struct kdentry *kdptr, *lptr, *CreateKDentry();
 void SortBucket();
 int i, j, k;

    bucket = CreateKDbucket(dim);
    bucket->norb.bucket.count = count;

    for (i=0,k=0; i!=count; i++) {
        kdptr = CreateKDentry(dim);
        kdptr->weight = weights[i];
        for (j=0; j!=dim; j++,k++) {
            kdptr->mean[j] = means[k];
            kdptr->wmean[j] = kdptr->mean[j] * kdptr->weight;
            kdptr->wsqmn[j] = kdptr->mean[j] * kdptr->wmean[j];
        }
        if (!i) {
            bucket->norb.bucket.lists[0] = kdptr;
            lptr = kdptr;
        } else {
            lptr->next[0] = kdptr;
            lptr = kdptr;
        }
    }
    SortBucket (bucket,dim);
}
return(bucket);
#include "fastpnn.h"

struct kdelem *CreateKDbucket(dim)
    
    int dim;
    
    /*
    * Function name:
    *     CreateKDBucket
    *
    * Purpose:
    *     Create a bucket for a kD tree
    *
    * Input arguments:
    *     dim    - dimensionality of the sample data
    *
    * Output arguments:
    *     None
    *
    * Returns:
    *     STACK    - Newly created bucket
    */

    
    struct kdelem *bucket;
    /* char *calloc(); */

    if (!(bucket = (struct kdelem *)calloc((unsigned)1,sizeof(struct kdelem))))
        fatal_message(KDMEMERR);
    if (!(bucket->norb.bucket.lists = (struct kdentry **)  
        calloc((unsigned)dim,sizeof(struct kdentry *)))))
        fatal_message(KDMEMERR);

    bucket->type = KDBUCKET;
    
    return(bucket);
}
`#include "fastpnn.h"

void DestroyLastBucket (bucket)
    
    struct kdelem *bucket;

/*
 * Function name:
 *  DestroyLastBucket
 *
 * Purpose:
 *  Destroy the last bucket in a tree
 *
 * Input arguments:
 *  bucket - bucket to be destroyed
 *
 * Output arguments:
 *  None
 *
 * Returns:
 *  Nothing
 */

{ void DestroyKDbucket(), DestroyKDentry();
    struct kdentry *entry, *next;

    entry = bucket->norb.bucket.lists[0];
    while (entry) [
        next = entry->next[0];
        DestroyKDentry(entry);
        entry = next;
    ]
    DestroyKDbucket(bucket);
}
#include "fastpnn.h"

void DestroyKDbucket (bucket)

    struct kdelem *bucket;

    /*
    * Function name:
    *    DestroyKDBucket
    *
    * Purpose:
    *    Destroy a kD tree bucket
    *
    * Input arguments:
    *    bucket - bucket to be destroyed
    *
    * Output arguments:
    *    None
    *
    * Returns:
    *    Nothing
    */

    { cfree((char *)bucket->norb.bucket.lists);
      cfree((char *)bucket);
    }
#include "fastpnn.h"

struct kdentry *CreateKDentry (dim)

    int dim;

    /*
     * Function name:
     *   CreateKDentry
     *   
     * Purpose:
     *   Create a kD tree bucket entry for holding a sample point
     *   
     * Input arguments:
     *   dim   - dimensionality of the sample data
     *   
     * Output arguments:
     *   None
     *   
     * Returns:
     *   STACK   - pointer to a bucket entry
     */

    {struct kdentry *entry;
     /* char *calloc(); */

        if (!(entry = (struct kdentry *)calloc((unsigned)1,sizeof(struct kdentry))))
            fatal_message(KDMEMERR);
        if (!(entry->next = (struct kdentry **)calloc((unsigned)dim,sizeof(struct kdentry *))))
            fatal_message(KDMEMERR);
        if (!(entry->mean = (float *)calloc((unsigned)dim,sizeof(float))))
            fatal_message(KDMEMERR);
        if (!(entry->wmean = (float *)calloc((unsigned)dim,sizeof(float))))
            fatal_message(KDMEMERR);
        if (!(entry->vrsqmn = (float *)calloc((unsigned)dim,sizeof(float))))
            fatal_message(KDMEMERR);

        return(entry);
    }
#include "fastpnni.h"

void DestroyKDentry (entry)
    struct kdentry *entry;

/*
 * Function name:
 *   DestroyKDentry
 *
 * Purpose:
 *   Destroy a kD tree bucket entry
 *
 * Input arguments:
 *   entry  - pointer to the entry to be destroyed
 *
 * Output arguments:
 *   None
 *
 * Returns:
 *   Nothing
 */

{ 
    if (entry) {
        cfree((char *)entry->next);
        cfree((char *)entry->mean);
        cfree((char *)entry->wmean);
        cfree((char *)entry->wsqmn);
        cfree((char *)entry);
    }
}

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#include "fastpnn.h"

struct kdelem *CreateKDnode()
{
    /*
     * Function name:
     *    CreateKDnode
     *
     * Purpose:
     *    Create a kD tree node
     *
     * Input arguments:
     *    Nothing
     *
     * Output arguments:
     *    None
     *
     * Returns:
     *    STACK - pointer to the newly created kD tree node
     */

    struct kdelem *node;
    /* char *calloc(); */

    if (!((node = (struct kdelem *)calloc((unsigned)1, sizeof(struct kdelem)))))
        fatal_message(KDMEMERR);

    node->type = KDNODE;

    return(node);
}
#include "fastpnn.h"

void DestroyKDnode(node)

    struct kdelem *node;

    /*
     * Function name:
     *   DestroyKDnode
     *
     * Purpose:
     *   Destroy a kD tree node
     *
     * Input arguments:
     *   node   - pointer to the entry to be destroyed
     *
     * Output arguments:
     *   None
     *
     * Returns:
     *   Nothing
     */

    { if (node)
        cfree((char *)node);
    }
#include "fastpnn.h"

void SortBucket (elem, dim)
{
    struct kdelem *elem;
    int dim;

    /*
     * Function name:
     * SortBucket
     *
     * Purpose:
     * Sort the entries in a kD tree bucket across each dimension separately
     *
     * Input arguments:
     * elem - pointer to the bucket containing the entries to be sorted
     * dim - dimensionality of the sample data
     *
     * Output arguments:
     * None
     *
     * Returns:
     * Nothing
     */

    struct kdentry *entry, **epbffr;
    void index();
    /* char *calloc(); */
    int i, j, count;

    count = elem->norb.bucket.count;

    if (!(epbffr = (struct kdentry **)calloc((unsigned)count,
                                sizeof(struct kdentry *)))))
        fatal_message(KDMEMERR);

    for (i=0; i<dim; i++) {
        for (j=0, entry=elem->norb.bucket.lists[0]; j<count; j++) {
            epbffr[j] = entry;
            entry = entry->next[0];
        }
        index(epbffr, &i);
        elem->norb.bucket.lists[i] = epbffr[0];
        for (j=1; j<count; j++)
            epbffr[j-1]->next[i] = epbffr[j];
            epbffr[(count - 1)]->next[i] = (struct kdentry *)0;
    }
    cfree((char *)pbfr);
}
#include "fastpnn.h"

void indxx(kdentry **epbfr, int *i)

/*
 * Function name:
 * indxx
 *
 * Purpose:
 * Sort an array of indices indx based on the data arrin using an indexed
 * version of a heap sort. Modified from Numerical Recipes indexx.
 *
 * Input arguments:
 * arrin - array of data used for sorting
 * n - number of entries in arrin
 *
 * Output arguments:
 * indx - Indices specifying the order of data in arrin
 *
 * Returns:
 * Nothing
 */

{ int l, j, ir, indx, i;
  float q;

  for (j = 0; j < n; j++)
    indx[j] = j;

  l = n >> 1;
  ir = n - 1;

  while (TRUE) {
    if (l > 0)
      q = arrin[(indx = indx[--l])];
    else {
      q = arrin[(indx = indx[ir])];
      indx[ir] = indx[0];
      if (--ir == 0) {
        indx[0] = indx;
        return;
      }
    }

    i = 1;
    j = ((l + 1) << 1) - 1;

    while (j <= ir) {
      if (j < ir && arrin[indx[j]] < arrin[indx[j + 1]])
        j++;
      if (q < arrin[indx[j]]) {
        indx[i] = indx[j];
        j = ((i = j) + 1);
      }
    }
  }
}

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else \ j = ir + 1;

\texttt{indx[i]} = \texttt{indxt};

\texttt{indx[i]}
#include "fastpnn.h"

void MergeDownKDtree(tree, ncntrds)
    struct kdtree *tree;
    int ncntrds;

    /*
     * Function name:
     *      MergeDownKDtree
     *
     * Purpose:
     *      Reduce a kD tree to a single bucket having ncntrds entries using the PNN
     *      algorithm
     *
     * Input arguments:
     *      tree - pointer to a kD tree
     *      ncntrds - desired number of entries after merging
     *
     * Output arguments:
     *      None
     *
     * Returns:
     *      Nothing
     */

    void CompressKDtreeo, BalanceKDtreeo;
    struct kdelem *CollapseKDnodeo;
    int nmerge, ntile, maxbktso;
    struct kdelem **bcktarray;
    /* char *calloc(); */

    maxbktso = tree->nentries / (BUCKETSIZE / 2);
    if (!((bcktarray = (struct kdelem **)calloc((unsigned)maxbktso,
                                                   sizeof(struct kdelem *)))))
        fatal_message(KDMEMERR);

    while (tree->nentries > ncntrds) {
        BalanceKDtreeo(tree, bcktarray);
        ntile = (KDMERGE * tree->nbuckets > 1) ? KDMERGE * tree->nbuckets : 1;
        nmerge = ((tree->nentries - ncntrds) < ntile) ?
                  (tree->nentries - ncntrds) : ntile;
        CompressKDtreeo(tree, nmerge, bcktarray);
    }
    if (tree->root->type == KDNODE)
        tree->root = CollapseKDnodeo(tree->root, tree->dim, &tree->nbuckets);
    free((char *)bcktarray);
}
#include "fastpnn.h"

void BalanceKDtree(tree, bcktarray)

    struct kdtree *tree;
    struct kdelem **bcktarray;

    /*
     * Function name:
     * BalanceKDtree
     *
     * Purpose:
     * Distribute the entries in a kD tree so that each bucket has
     * approximately the same number of entries
     *
     * Input arguments:
     * tree - pointer to a kD tree
     *
     * Output arguments:
     * bcktarray - array used to retain a pointer to each bucket after balancing
     *
     * Returns:
     * Nothing
     */

    struct kdelem *CollapseKDnode(), *SplitBucket(), **bptr;
    float *mean, *vvar;
    /* char *calloco; */

    if (!(mean = (float *)calloc((unsigned)tree->dim,sizeof(float))))
        fatal_message(KDHEMERR);
    if (!vvar =(float *)calloc((unsigned)tree->dim,sizeof(float))))
        fatal_message(KDMEMERR);

    if (tree->root->type == KDNODE)
        tree->root = CollapseKDnode(tree->root, tree->dim, &tree->nbuckets);

    bcktarray[0] = tree->root;
    bptr = &bcktarray[1];

    tree->root =
        SplitBucket(tree->root, tree->dim, &tree->nbuckets, &bptr, mean, vvar);

    cfree((char *)mean);
    cfree((char *)vvar);
#include "fastpnn.h"

struct kdelem *CollapseKDnode(elem,dim,bctr)

    struct kdelem *elem;
    int dim, *bctr;

/*
 * Function name:
 * CollapseKDnode
 *
 * Purpose:
 * Recursive function used to collapse the entries in a kD tree into a
 * single bucket
 *
 * Input arguments:
 * elem - pointer to a kD tree node to be collapsed
 * dim - dimension of the data within the tree
 *
 * Output arguments:
 * bctr - pointer to a counter used to keep track of the total number
 * of buckets in the tree
 *
 * Returns:
 * STACK - pointer to the bucket resulting from the collapse
 */

struct kdentry **entptr, *lentry, *rentry;
struct kdelem *bucket;
void DestroyKDnode(), DestroyKDbucket();
int i;

if (elem->norb.node.lower->type != KDBUCKET)
    elem->norb.node.lower = CollapseKDnode(elem->norb.node.lower,dim,bctr);
if (elem->norb.node.upper->type != KDBUCKET)
    elem->norb.node.upper = CollapseKDNode(elem->norb.node.upper,dim,bctr);

bucket = elem->norb.node.lower;

for (i=0; i<dim; i++) {
    entptr = &(elem->norb.node.lower->norb.bucket.lists[i]);
    lentry = elem->norb.node.lower->norb.bucket.lists[i];
    rentry = elem->norb.node.upper->norb.bucket.lists[i];
    while (lentry && rentry) {
        if (lentry->mean[i] < rentry->mean[i]) {
            *entptr = lentry;
            entptr = &(lentry->next[i]);
            lentry = lentry->next[i];
        }
        else {
            *entptr = rentry;
            entptr = &(rentry->next[i]);
            rentry = rentry->next[i];
        }
    }
}

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```c
}  
if (lentry) {
    while (lentry) {
        *entptr = lentry;
        entptr = &(lentry->next[i]);
        lentry = lentry->next[i];
    }
}

if (rentry) {
    while (rentry) {
        *entptr = rentry;
        entptr = &(rentry->next[i]);
        rentry = rentry->next[i];
    }
}
}

bucket->norb.bucket.count = elem->norb.node.lower->norb.bucket.count +
                           elem->norb.node.upper->norb.bucket.count;
DestroyKDbucket(elem->norb.node.upper);
DestroyKDnode (elem);
(*bctr) --;
return(bucket);
```


```c
#include "fastpnn.h"

struct kdelem *SplitBucket(oldbucket, dim, bctr, bptr, mean, wvar)
{
    struct kdelem *oldbucket, ***bptr;
    int dim, *bctr;
    float *mean, *wvar;

    /*
    * Function name:
    * SplitBucket
    *
    * Purpose:
    * Recursive function used to split a kD tree bucket into two smaller
    * buckets having half as many entries
    *
    * Input arguments:
    * oldbucket - pointer to kD tree bucket to be split
    * dim - dimension of the data within the tree
    * mean - scratch array used for calculating bucket means
    * wvar - scratch array used for calculating bucket weighted variances
    *
    * Output arguments:
    * bctr - pointer to a counter used to keep track of the total number
    * of buckets in the tree
    * bptr - pointer to an array of pointers to buckets in the tree
    *
    * Returns:
    * STACK - pointer to the node resulting from the split, or the original
    * bucket if the number of entries in the bucket is small enough
    */

    struct kdelem *newnode, *newbucket, *CreateKDbucket();
    struct kdentry **oldptr, **newptr, *entry;
    int i, j, bcount, medindx;
    void GetBucketStats();

    if (oldbucket->norb.bucket.count > BUCKETSIZE) {
        GetBucketStats(oldbucket, dim, mean, wvar);
        for (i=1, j=0; i<dim; i++)
            if (wvar[i] > wvar[j])
                j = i;

        bcount = oldbucket->norb.bucket.count;
        medindx = (bcount + 1) / 2; /* Uneven splits go left */
        newnode = CreateKDnode();
        newnode->norb.node.dindx = j;
        newbucket = CreateKDbucket(dim);
        newnode->norb.node.lower = oldbucket;
    }
}
```
newnode->norb.node.upper = newbucket;

(*bctr) ++;
(**bptr) = newbucket;
(*bptr) ++;

for (i=0, entry=oldbucket->norb.bucket.lists[j]; i<medindx; i++) {
    entry->splitleft = TRUE;
    entry = entry->next[j];
}

for (i=medindx; i<bcount; i++) {
    entry->splitleft = FALSE;
    entry = entry->next[j];
}

oldbucket->norb.bucket.count = medindx;
newbucket->norb.bucket.count = bcount - medindx;

for (i=0; i!=dim; i++) {
    oldptr = &oldbucket->norb.bucket.lists[i];
    newptr = &newbucket->norb.bucket.lists[i];
    entry = oldbucket->norb.bucket.lists[i];
    while (entry) {
        if (entry->splitleft) {
            *oldptr = entry;
            oldptr = (struct kdentry **)(entry->next[i]);
        }
        else {
            *newptr = entry;
            newptr = (struct kdentry **)(entry->next[i]);
        }
        entry = entry->next[i];
    }
    *oldptr = (struct kdentry *)0;
    *newptr = (struct kdentry *)0;
}

newnode->norb.node.lower =
    SplitBucket(newnode->norb.node.lower, dim, bctr, bptr, mean, vvar);
newnode->norb.node.upper =
    SplitBucket(newnode->norb.node.upper, dim, bctr, bptr, mean, vvar);

    return(newnode);
} else
    return(oldbucket);
}
#include "fastpnn.h"

void GetBucketStats (elem, dim, mean, wvar)
{
    struct kdelem *elem;
    int dim;
    float *mean, *wvar;

    /*
    * Function name:
    *   GetBucketStats
    *
    * Purpose:
    *   Calculate the k dimensional means and weighted variances for a bucket
    *
    * Input arguments:
    *   elem     - pointer to the kD tree bucket for which the statistics are
    *              to be calculated
    *   dim      - dimension of the data within the tree
    *
    * Output arguments:
    *   mean     - array used for calculating bucket means
    *   wvar     - array used for calculating bucket weighted variances
    *
    * Returns:
    *   Nothing
    */

    struct kdentry *entry;
    float wgtsum;
    int i;

    wgtsum = 0.0;

    for (i=0; i!=dim; i++) {
        mean[i] = 0.0;
        wvar[i] = 0.0;
    }

    entry = elem->norb.bucket.lists[0];
    while (entry) {
        wgtsum += entry->weight;
        for (i=0; i!=dim; i++) {
            mean[i] += entry->wmean[i];
            wvar[i] += entry->wsqmn[i];
        }
        entry = entry->next[0];
    }

    for (i=0; i!=dim; i++) {
        mean[i] /= wgtsum;
        wvar[i] = (wvar[i] / wgtsum) - (mean[i] * mean[i]);
    }
}
#include "fastpnn.h"

static int BucketCompare(one,two)

    struct kdelem **one, **two;

/*
 * Function name:
 *   BucketCompare
 *
 * Purpose:
 *   Function used by the UNIX qsort routine to compare merge distortions of
two buckets
 *
 * Input arguments:
 *   one       - pointer to a pointer to the first kD tree bucket used in
 *                the comparison
 *   two       - pointer to a pointer to the second kD tree bucket used in
 *                the comparison
 *
 * Output arguments:
 *   None
 *
 * Returns:
 *   STACK     - the value 1 if distortion(one) > distortion(two)
 *               the value 0 if distortion(one) = distortion(two)
 *               the value -1 if distortion(one) < distortion(two)
 */

    if   ((*one)->norb.bucket.distort < (*two)->norb.bucket.distort)
        return(-1);
    else if ((*one)->norb.bucket.distort == (*two)->norb.bucket.distort)
        return( 0);
    else
        return( 1);
#include "fastpnn.h"

void CompressKDtree (tree, nmerge, bcktarray)
{
    struct kdtree *tree;
    int nmerge;
    struct kdelem **bcktarray;

    /*
     * Function name:
     * CompressKDtree
     *
     * Purpose:
     * Function used to merge bucket entry pairs into single bucket entries for
     * a fixed fraction of the total number of buckets
     *
     * Input arguments:
     * tree - pointer to the kD tree undergoing the merge
     * nmerge - number of bucket pairs to merge
     * bcktarray - array of pointers to all buckets in the tree
     *
     * Output arguments:
     * None
     *
     * Returns:
     * Nothing
     *
     */

    void AssessCandidate(), ReduceKDbucket();
    int i, ncount, BucketCompare;

    for (i=0,ncount=0; i!=tree->nbuckets; i++)
    AssessCandidate(bcktarray[i],tree->diri,bcktarray,&ncount);

    /* Handle end game situations */
    if (nmerge > ncount)
        nmerge = ncount;

    if (ncount > 1)
        qsort((char *)bcktarray,ncount,sizeof(struct kdelem *),BucketCompare);

    for (i=0; i!=nmerge; i++)
        ReduceKDbucket(bcktarray[i],tree->dim);

    tree->nentries -= nmerge;
}
#include "fastpnn.h"

void AssessCandidate(elem, dim, barray, ncount)

    struct kdelem *elem, **barray;
    int dim, *ncount;

    /*
     * Function name:
     *     AssessCandidate
     *
     * Purpose:
     *     Determine the minimal distortion than can be produced by merging a pair
     *     of bucket entries
     *
     * Input arguments:
     *     elem - pointer to the kD tree bucket under evaluation
     *     dim - dimension of the data within the entries
     *
     * Output arguments:
     *     barray - array of pointers to all buckets that can be merged
     *     ncount - pointer to counter used to keep track of the total number
     *              of buckets that can be merged
     *
     * Returns:
     *     Nothing
     *
    */

    struct kdentry *ientry, *jentry;
    float reduction, dotprd, diff;
    int i, j, k, firsttime;

    firsttime = TRUE;
    if (elem->norb.bucket.count > 1) {
        ientry = elem->norb.bucket.lists[0];
        for (i=0; i<elem->norb.bucket.count-1; i++, ientry=ientry->next[0]) {
            jentry = ientry->next[0];
            for (j=i+1; j<elem->norb.bucket.count; j++, jentry=jentry->next[0]) {
                for (k=0, dotprd=0.0; k<dim; k++) {
                    diff = ientry->mean[k] - jentry->mean[k];
                    dotprd += diff * diff;
                }
                reduction = dotprd * ientry->weight * jentry->weight / 
                            (ientry->weight + jentry->weight);
                if ((reduction < elem->norb.bucket.distort) || firsttime) {
                    elem->norb.bucket.distort = reduction;
                    elem->norb.bucket.entrya = ientry;
                    elem->norb.bucket.entryb = jentry;
                    firsttime = FALSE;
                }
            }
        }
    }

    barray[(*ncount)++] = elem;
#include "fastpnn.h"

void ReduceKDbucket(elem,dim)
    struct kdelem *elem;
    int dim;

    /*
    * Function name:
    * ReduceKDbucket
    *
    * Purpose:
    * Merges a pair of bucket entries into a single entry
    *
    * Input arguments:
    * elem       - pointer to the kD tree bucket whose entries are to be merged
    * dim        - dimension of the data within the entries
    *
    * Output arguments:
    * None
    *
    * Returns:
    * Nothing
    *
    */

    struct kdentry *ientry, *jentry, **leptr;
    float newweight;
    int i, rmcnt;

    ientry = elem->norb.bucket.entrya;
    jentry = elem->norb.bucket.entryb;

    /* Remove ientry, jentry from the list */
    for (i=0; i!=dim; i++) {
        for (leptr = &(elem->norb.bucket.lints[i]), rmcnt=0; rmcnt!=2;) {
            if ((*leptr==jentry)) {
                *leptr = (*leptr)->next[i];
                rmcnt++;
            } else
                leptr = &((*leptr)->next[i]);
    }

    newweight = ientry->weight + jentry->weight;
    for (i=0; i!=dim; i++) {
        ientry->mean[i] = (ientry->mean[i] * ientry->weight +
            jentry->mean[i] * jentry->weight) / newweight;
        ientry->wmean[i] = ientry->mean[i] * newweight;
        ientry->wsqmn[i] = ientry->mean[i] * ientry->wmean[i];
    }
    ientry->weight = newweight;
/* Reinsert ientry into the list in the proper order */

for (i=0; i<dim; i++) {
    for (leptr = &(elem->norb.bucket.lists[i]);
        (*leptr && ((*leptr)->rneanji] < ientry->mean[i]));
        leptr = &((*leptr)->next[i]));
    ientry->next[i] = *leptr;
    *leptr = ientry;
}

elem->norb.bucket.count--; /* Decrement the total entry count */
DestroyKDentry(jentry); /* Free up jentry memory */

void fatal_message(char string[])
{
    printf("%s\n",string);
    return;
}
/* This is the header file, "timer.h", which contains the declarations
 * (or function prototypes) for the VAX/VMS timing routines
 */

int init_timer(void);

int elapsed_time(int starting_time);

int identity (int arg);
#include "timer.h"
#include <time.h>
#include <stdio.h>

/* This file contains the VAX/VMS timing routines. Note that the
 * functions init_timer and elapsed_time make use of a predefined
 * C function called "times". Function times returns the accumulated
 * CPU time in a predefined time structure called tbuffer_t.
 * */

tbuffer_t *init_time_ptr, *final_time_ptr;
tbuffer_t buffer, init_time, final_time;

int init_timer (void)
{
    int current_time;
    init_time_ptr = &init_time;
    times(init_time_ptr);
    current_time = (init_time_ptr->proc_user_time) * 10000;
    return current_time;
}

int elapsed_time(int start_time)
{
    int time_elapsed;
    final_time_ptr = &final_time;
    times(final_time_ptr);
    time_elapsed = ((final_time_ptr->proc_user_time) * 10000) - start_time;
    return time_elapsed;
}

int identity (int arg)
{
    int some_value = 0;
    some_value = some_value + arg;
    return some_value;
}
/* This is the header file, "timer.h", which contains the declarations
 * (or function prototypes) for the MIPS/UNIX timing routines.
 */

long int init_timer(void);
long int elapsed_time(void);
int identity (int arg);
#include "timer.h"
#include <time.h>
#include <stdio.h>

/* This file contains the MIPS/UNIX timing routines. Note that the
functions init_timer and elapsed_time make use of the predefined
C function called "clock". Function clock returns the amount of
CPU time used since the first call to clock. */

long int init_timer (void)
{
    long int current_time;
    current_time = clock();
    return current_time;
}

long int elapsed_time(void)
{
    long int time_elapsed;
    time_elapsed = clock();
    return time_elapsed;
}

int identity (int arg)
{
    int some_value = 0;
    some_value = some_value + arg;
    return some_value;
}
| 58.000000 | 19.000000 | 62.000000 |
| 59.000000 | 19.000000 | 74.000000 |
| 60.000000 | 19.000000 | 70.000000 |
| 57.000000 | 20.000000 | 67.000000 |
| 58.000000 | 20.000000 | 90.000000 |
| 59.000000 | 20.000000 | 91.000000 |
| 60.000000 | 20.000000 | 78.000000 |
| 61.000000 | 20.000000 | 52.000000 |
| 56.000000 | 21.000000 | 75.000000 |
| 57.000000 | 21.000000 | 76.000000 |
| 58.000000 | 21.000000 | 101.000000 |
| 59.000000 | 21.000000 | 91.000000 |
| 60.000000 | 21.000000 | 67.000000 |
| 56.000000 | 22.000000 | 75.000000 |
| 57.000000 | 22.000000 | 100.000000 |
| 58.000000 | 22.000000 | 108.000000 |
| 59.000000 | 22.000000 | 104.000000 |
| 60.000000 | 22.000000 | 92.000000 |
| 61.000000 | 22.000000 | 72.000000 |
| 56.000000 | 23.000000 | 84.000000 |
| 57.000000 | 23.000000 | 135.000000 |
| 58.000000 | 23.000000 | 159.000000 |
| 59.000000 | 23.000000 | 165.000000 |
| 60.000000 | 23.000000 | 155.000000 |
| 61.000000 | 23.000000 | 124.000000 |
| 62.000000 | 23.000000 | 61.000000 |
| 56.000000 | 24.000000 | 135.000000 |
| 57.000000 | 24.000000 | 164.000000 |
| 58.000000 | 24.000000 | 190.000000 |
| 59.000000 | 24.000000 | 196.000000 |
| 60.000000 | 24.000000 | 185.000000 |
| 61.000000 | 24.000000 | 151.000000 |
| 62.000000 | 24.000000 | 74.000000 |
| 55.000000 | 25.000000 | 59.000000 |
| 56.000000 | 25.000000 | 109.000000 |
| 57.000000 | 25.000000 | 173.000000 |
| 58.000000 | 25.000000 | 200.000000 |
| 59.000000 | 25.000000 | 206.000000 |
| 60.000000 | 25.000000 | 194.000000 |
| 61.000000 | 25.000000 | 160.000000 |
| 62.000000 | 25.000000 | 81.000000 |
| 63.000000 | 25.000000 | 58.000000 |
| 36.000000 | 26.000000 | 52.000000 |
| 56.000000 | 26.000000 | 105.000000 |
| 57.000000 | 26.000000 | 165.000000 |
| 58.000000 | 26.000000 | 191.000000 |
| 59.000000 | 26.000000 | 197.000000 |
| 60.000000 | 26.000000 | 185.000000 |
| 61.000000 | 26.000000 | 152.000000 |
| 62.000000 | 26.000000 | 80.000000 |
| 63.000000 | 26.000000 | 58.000000 |
| 36.000000 | 27.000000 | 60.000000 |
| 37.000000 | 27.000000 | 73.000000 |
| 40.000000 | 27.000000 | 85.000000 |
| 41.000000 | 27.000000 | 94.000000 |
APPENDIX B

ADA CODED FASTPNN BENCHMARK SOURCE CODE
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**DESTROY PKG**

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**VAX/VMS TIMER SPECIFICATION**

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**MIPS TIMER SPECIFICATION**

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**READ DATA**

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with timer;
with FASTPNN;
with READ DATA;
with text io; use text io;
with Data_Struct_Pkg; use Data_Struct_Pkg;
procedure main is

-- Procedure Name: Main
-- Purpose: This is the main routine for the FASTPNN algorithm.
-- The user is prompted to input the name of the input
-- file, the name of the output file, and the number of
-- input vector data values. External procedure
-- READ DATA is called by Main to read in the values
-- from the input data file. Main performs the timing
-- of the FastPNN algorithm (by calling timing
-- routines contained within Timer_Pkg) and outputs the
-- results.
--
LENTHIN : INTEGER;
LENTHOUT : INTEGER;
POSITIONS_LAST : INTEGER;
RESULTS_LAST : INTEGER;
WEIGHTS_LAST : INTEGER;
count : integer;
dim : integer;
ncntrds : integer;
INNAME : STRING(1 .. 80);
OUTNAME : STRING(1 .. 80);
VECTOR_NUM : INTEGER;

loop_count : constant := 1;
fastpnn_elapsed : integer;
fastpnn_timer : timer.microsec_timer;

dummy_timer : timer.microsec_timer;
dummy_elapsed_time : integer;
dummy_arg : integer;

INFILE : FILE-TYPE;
OUTFILE : FILE-TYPE;

package float io is new text io.float_io(float);
package int io is new text io.integer_io(integer);

procedure printarray (OUTFILE : in out FILE-TYPE;
array : in means_array_type;
dim : in integer; count : in integer) is

begin
  k := 0;

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for i in 0 .. count - 1 loop
    put(OUTFILE, " ");
    for j in 0 .. dim - 1 loop
        float io.put(OUTFILE, arrayy(k));
        k := k + 1;
        if (j /= dim-1) then
            put(OUTFILE, " ");
        else
            put_line(OUTFILE, " ");
        end if;
    end loop;
end loop;
end printarray;

begin -- MAIN

PUT_LINE("Enter Name of Input File. ");
GET_LINE(INNAME, LENGTHIN);
PUT_LINE("Enter Name of Output File ");
GET_LINE(OUTNAME, LENGTHOUT);
PUT_LINE("Enter the number of input vectors ");
INT IO.GET(VECTORNUM);
OPEN(INFILE, IN_FILE, INNAME(1 .. LENGTHIN));
CREATE(OUTFILE, OUT_FILE, OUTNAME(1 .. LENGTHOUT));

POSITIONS_LAST := 2 * VECTOR_NUM - 1;
RESULTS_LAST := 2 * VECTOR_NUM - 1;
WEIGHTS_LAST := VECTOR_NUM - 1;

DECLARE

positions : means_array_type(0 .. POSITIONS_LAST);
results : means_array_type(0 .. RESULTS_LAST);
weights : weights_array_type(0 .. WEIGHTS_LAST);

begin

    count := weights'length;
    dim := positions'length/count;

READ_DATA (INFILE, positions, weights);

ncntrds := 4; -- number of desired output vectors

-- first time the dummy loop
--
timer.init_timer(dummy_timer);
for i in 1 .. loop_count loop
    dummy_arg := timer.identity(dummy_arg);
end loop;
if timer.always_true then
    dummy_elapsed_time := timer.elapsed_time(dummy_timer);
end if;
-- now time the routine of interest
--

timer.init_time(fastpnn_timer);
for i in 1..loop_count loop
    FastPNN(positions, weights, count, dim, ncentrs, results);
    dummy_arg := timer.identity(dummy_arg);
end loop;

if time.always_true then
    fastpnn_elapsed := timer.elapsed_time(fastpnn_timer);
end if;

PUT(OUTFILE, "FastPNN executes in ");
FLOAT_IO.PUT(OUTFILE, float((fastpnn_elapsed -
    dummy_elapsed_time)) * float(loop_count));
text_io.put_line (OUTFILE, " microseconds.");
PUT_LINE(OUTFILE, "Returned results");
printarray (OUTFILE, results, dim, ncentrs);
CLOSE(OUTFILE);
end;

end main;
with Data_Struct_Pkg; use Data_Struct_Pkg;
with Build_Pkg;
with MergeDown_Pkg;
with Destroy_Pkg;

procedure FastPNN (means : in out means_array_type;
weights : in out weights_array_type;
count : in integer;
dim : in integer;
ncntrds : in integer;
centroids : out means_array_type) is

  -- Procedure name: FastPNN
  -- Purpose: Outermost routine for the Pairwise Nearest Neighbor
  -- Clustering algorithm
  -- Input arguments:
  -- means - sample point array
  -- weights - sample weight array
  -- count - number of samples
  -- dim - dimensionality of the sample data
  -- ncnntrds - target number of clusters to form the data
  -- Output arguments
  -- centroids - cluster vector results from FASTPNN algorithm

entryy : kdentry_ptr_type;
tree : kdtree_ptr_type;
k : integer;

begin

  Build_Pkg.BuildKDtree(means, weights, count, dim, tree);
  MergeDown_Pkg.MergeDownKDtree(tree, ncnntrds);

  entryy := tree.root.bucket.lists_array(O);
  k := 0;
  for i in 0 .. ncnntrds - 1 loop
      for j in 0 .. dim - 1 loop
          centroids(k) := entryy.mean_array(j);
          k := k + 1;
      end loop;
      entryy := entryy.next_array(O);
  end loop;
  Destroy_Pkg.DestroyKDtree(tree);

end FastPNN;
package Data_Struct_Pkg is

-- This package specification contains the declarations of
-- data types used by all modules in the FASTPNN routine

TRUEE : constant := -1;
FALSEE : constant := 0;
KDNODEE : constant := 0;
KDBUCKETT : constant := 1;
BUCKETSIZE : constant := 8;
KDMERGE : constant := 0.5;
dim : constant := 2;

-- Data Structures defined in the main program

type means_array_type is array (integer range <>) of float;
type weights_array_type is array (integer range <>) of float;

-- data structure used in CollapseKDnode
type integer_ptr_type is access integer;

-- data structures needed in indxx
type float_array_type is array (integer range <>) of float;
type integer_array_type is array (integer range <>) of integer;

type Kdentry;
type Kdentry_ptr_type is access Kdentry;
type Kdentry_ptr_array_type is array (integer range <>) of Kdentry_ptr_type;
type mean_array_type is array (integer range <>) of float;
type wmean_array_type is array (integer range <>) of float;
type wsqmn_array_type is array (integer range <>) of float;
type wvar_array_type is array (integer range <>) of float;

type Kdentry is
record
next_array : Kdentry_ptr_array_type(0 .. dim - 1);
splitleft : integer;
weight : float;
mean_array : mean_array_type(0 .. dim - 1);
wmean_array : wmean_array_type(0 .. dim - 1);
wsqmn_array : wsqmn_array_type(0 .. dim - 1);
end record;

type data_structure_type is (kdnode_type, kdbucket_type);
type kdelem(data_structure : data_structure_type);
type kdelem_ptr_type is access kdelem;

-- Data structure kdelem_ptr_array_type used in BalanceKDtree

type kdelem_ptr_array_type is array (integer range <>)
of kdelem_ptr_type;

```pli

type kdbucket is
record
  count       : integer;
  lists_array : Kdentry_ptr_array_type(0 .. dim - 1);
  entrya      : Kdentry_ptr_type;
  entryb      : Kdentry_ptr_type;
  distort     : float;
end record;

type kdbucket_ptr_type is access kdbucket;

type kdelem (data_structure : data_structure_type) is
record
  typee       : integer;
  case data_structure is
    when kdnode_type =>
      node        : kdnode;
    when kdbucket_type =>
      bucket      : kdbucket;
  end case;
end record;
norb_n : kdelem(kdnode_type);
norb_b : kdelem(kdbucket_type);

type kdtree is
record
  dim        : integer;
  root       : kdelem_ptr_type;
  nbuckets   : integer;
  nentries   : integer;
end record;

type kdtree_ptr_type is access kdtree;

end Data_Struct_Pkg;
```
with Data_Struct_Pkg; use Data_Struct_Pkg;
package Build_Pkg is

-- Package Specification: Build_Pkg contains the declaration of
-- all subprograms which are available for building and
-- initialization of the K-d data structure.

procedure BuildKDtree (means : in out means_array_type;
weights : in out weights_array_type;
count : in integer;
dim : in integer;
tree : out Kdtree_ptr_type);

function CreateKDbucket (dim : integer) return kdelem_ptr_type;

end Build_Pkg;
package body Build_Pkg is

  function CreateKDbucket (dim : integer) return kdelem_ptr_type
  is separate;

  procedure Indxx (arrin : in float_array_type;
      indx : out integer_array_type;
      n : in integer) is separate;

  procedure SortBucket (elew : in kdelem_ptr_type;
      dim : in integer) is separate;

  function CreateKDentry (dim : in integer) return kdentry_ptr_type
  is separate;

  procedure CreateFirstBucket (means : in out means_array_type;
      weights : in out weights_array_type;
      count : in integer;
      dim : in integer;
      bucket : out kdelem_ptr_type)
  is separate;

  function CreateKDtree (dim : integer) return kdtree_ptr_type
  is separate;

  procedure BuildKDtree (means : in out means_array_type;
      weights : in out weights_array_type;
      count : in integer;
      dim : in integer;
      tree : out Kdtree_ptr_type) is separate;

end Build_Pkg;
procedure BuildKDtree (means : in out means_array_type;
weights : in out weights_array_type;
count : in integer;
dim : in integer;
tree : out Kdtree_ptr_type) is

-- Procedure name: BuildKdtree

-- Purpose: Constructs an initial KD tree from the sample data

-- Input arguments:
--   means - sample point array
--   weights - sample weight array
--   count - number of samples
--   dim - dimensionality of the sample data

-- Output arguments:
--   pointer to a kdtree

begin -- BuildKDtree

temp_tree : kdtree_ptr_type;
bucket : kdelem_ptr_type;

begin -- BuildKDtree

temp_tree := CreateKDtree (dim);
CreateFirstBucket (means, weights, count, dim, bucket);
temp_tree.root := bucket;
temp_tree.nbuckets := 1;
temp_tree.nentries := count;
tree := temp_tree;
end BuildKDtree;
separate (Build_Pkg)
procedure CreateFirstBucket (means : in out means_array_type;
weights : in out weights_array_type;
   count : in integer;
    dim : in integer;
   bucket : out kdelem_ptr_type) is

-- Procedure name:
-- CreateFirstBucket

-- Purpose:
-- Create and initialize the first bucket in a KD tree

-- Input arguments:
-- means - sample point array
-- weights - sample weight array
-- count - number of samples
-- dim - dimensionality of the sample data

-- Output arguments:
-- bucket - pointer to first bucket in the Kdtree

mean, wvar : mean_array_type(0 .. dim -1);
kdptr, lptr : kdeentry_ptr_type;
KDPTRO, KDPTR1 : K丁ETY_PTR_TYPE;
k : integer;
tempbucket : Kdelem_ptr_type;

begin -- CreateFirstBucket

   tempbucket := CreateKDbucket(dim);
tempbucket.bucket.count := count;

   k := 0;
   for i in 0 .. (count - 1) loop
      kdptr := CreateKDentry(dim);
      kdptr.weight := weights(i);
      for j in 0 .. (dim - 1) loop
         kdptr.mean_array(j) := means(k);
         kdptr.vmean_array(j) := kdptr.mean_array(j) * kdptr.weight;
         kdptr.vsqmn_array(j) := kdptr.mean_array(j) * 
                                   kdptr.wmean_array(j);
      end loop;
      k := k + 1;
   end loop;
   if (i=0) then
      tempbucket.bucket.lists_array(0) := kdptr;
lptr := kdptr;
   else
      lptr.next_array(0) := kdptr;
lptr := kdptr;
   end if;
end loop;

SortBucket (tempbucket, dim);

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bucket := tempBucket;
end CreateFirstBucket;
with Data_Struct_Pkg; use Data_Struct_Pkg;
separate (Build_Pkg)
function CreateKDbucket (dim : integer) return kdelem_ptr_type is

-- Function name:
-- CreateKDbucket

-- Purpose:
-- Create a bucket for a KD tree

-- Input arguments
-- dim - dimensionality of the sample data

-- Output arguments
-- None

-- Returns:
-- returns pointer to new created bucket

bucket : kdelem_ptr_type;

begin

bucket := new kdelem(kdbucket_type);
bucket.type := KDBUCKETT;
return bucket;

end CreateKDbucket;
separate (Build_Pkg)
function CreateKDentry (dim : in integer) return kdentry_ptr_type is

-- Function name:
-- CreateKDentry

-- Purpose:
-- Create a KD tree bucket entry for holding a sample point

-- Input arguments:
-- dim - dimensionality of the sample data

-- Output arguments:
-- None

-- Returns:
-- pointer to a bucket entry

entryy : kdentry_ptr_type;
begin

    entryy := new Kdentry;
    return entryy;

end CreateKDentry;
function CreateKDtree (dim : integer) return kdtree_ptr_type is

-- Function name:
-- CreateKDtree

-- Purpose:
-- dynamically allocates storage space for a KD tree data structure

-- Input Arguments:
-- dim - dimensionality of the tree data

-- Output arguments
-- None

-- Returns:
-- pointer to a KDtree

begin
  tree := new kdtree;
  tree.dim := dim;
  return tree;
end CreateKDtree;
procedure Indxx (arrin : in float_array_type;
    indx : out integer_array_type;
    n : in integer) is

-- Procedure name: Indxx
-- Purpose: Sort an array of indeces indx based on the data arrin
-- using an indexed version of a heap sort. Modified from
-- Numerical Recipes indxx

-- Input Arguments:
-- arrin - array of data used for sorting
-- n - number of entries in arrin
-- Output arguments:
-- indx - Indices specifying the order of data in arrin

j, i, l, ir, indxt : integer;
q : float;
indxtemp : integer_array_type(0..n-1);

indx_j, indx_j_plus_1 : integer;
arrin_j, arrin_j_plus_1 : float;

begin

for k in 0 .. n - 1 loop
    indxtemp(k) := k;
end loop;

l := n/2;
ir := n - 1;
while TRUE loop
    if l > 0 then
        l := l - 1;
        indxt := indxtemp(l);
        q := arrin(indxt);
    else
        indxt := indxtemp(ir);
        q := arrin(indxt);
        indxtemp(ir) := indxtemp(0);
        ir := ir - 1;
        if ir = 0 then
            indxtemp(0) := indxt;
            exit;
        end if;
    end if;

    i := 1;
    j := 2 * (l + 1) - 1;

end loop;

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while (j <= ir) loop
    if (j < ir and then arrin(indxtemp(j)) <
        arrin(indxtemp(j + 1))) then
        j := j + 1;
    end if;
    if (q < arrin(indxtemp(j))) then
        indxtemp(i) := indxtemp(j);
        i := j;
        j := j + 1 + 1;
    else
        j := ir + 1;
    end if;
end loop;
indxtemp(i) := indxt;
end loop;
indx := indxtemp;
end Indxx;
procedure SortBucket (elem : in kdelem_ptr_type;
               dim : in integer) is

  -- Procedure name: Sortbucket
  -- Purpose: Sort the entries in a KD tree bucket across
each dimension separately
  -- Input arguments:
  --   elem - pointer to the bucket containing the entries
to be sorted
  --   dim - dimensionality of the sample data
  -- Output arguments: None

  entryy : kdentry_ptr_type;
  epbfr : kdentry_ptr_array_type(0 .. elem.bucket.count-1);
  mnbfr : float_array_type(0 .. elem.bucket.count-1);
  inbfr : integer_array_type(0 .. elem.bucket.count-1);
  count : integer;

begin

  count := elem.bucket.count;
  for i in 0 .. dim - 1 loop
    entryy := elem.bucket.lists_array(i);
    for j in 0 .. count-1 loop
      mnbfr(j) := entryy.mean_array(i);
      epbfr(j) := entryy;
      entryy := entryy.next_array(0);
    end loop;
    Index(mnbfr, inbfr, count);
  end loop;

  elem.bucket.lists_array(i) := epbfr(inbfr(0));
  for j in 1 .. count - 1 loop
    epbfr(inbfr(j-1)).next_array(i) := epbfr(inbfr(j));
  end loop;
  epbfr(inbfr(count - 1)).next_array(i) := null;
end loop;

end SortBucket;
with Data_Struct_Pkg; use Data_Struct_Pkg;
package MergeDown_Pkg is

-- Package specification Build_PKG contains the declarations
-- of all subprograms which are available for reducing the K-d
-- tree built in module BuildKDtree to the the specified number
-- of output centroids

procedure MergeDownKDtree (tree : in kdtree_ptr_type;
                           ncntrds : in integer);

end MergeDown_pkg;
with Destroy_Pkg; use Destroy_Pkg;
with Build_Pkg; use Build_Pkg;
package body MergeDown_Pkg is

procedure CollapseKDnode (elem : in out kdelem_ptr_type;
  dim : in integer;
  bctr : in out integer) is separate;

procedure GetBucketStats (elem : in kdelem_ptr_type;
  dim : in integer;
  mean : in out mean_array_type;
  wvar : in out wvar_array_type) is separate;

function CreateKDnode return kdelem_ptr_type is separate;

procedure SplitBucket (oldbucket : in out kdelem_ptr_type;
  dim : in integer;
  bctr : in out integer;
  bcktarray : in out kdelem_ptr_array_type;
  bptr : in out integer;
  mean : in out mean_array_type;
  wvar : in out wvar_array_type) is separate;

procedure BalanceKDtree (tree : in kdtree_ptr_type;
  bcktarray : in out kdelem_ptr_array_type) is separate;

procedure AssessCandidate (elem : in kdelem_ptr_type;
  dim : in integer;
  barray : in out kdelem_ptr_array_type;
  ncount : in out integer) is separate;

function BucketCompare (one : Kdelem_ptr_type;
  two : Kdelem_ptr_type) return boolean is separate;

procedure Quicksort (bcktarray : in out Kdelem_ptr_array_type) is separate;

procedure ReduceKDbucket (elem : in kdelem_ptr_type;
  dim : in integer) is separate;

procedure CompressKDtree (tree : in kdtree_ptr_type;
  nmerge : in integer;
  bcktarray : in out kdelem_ptr_array_type) is separate;

procedure MergeDownKDtree (tree : in kdtree_ptr_type;
  ncntrds : in integer) is separate;

end MergeDown_Pkg;

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procedure AssessCandidate (elem : in kdelem_ptr_type; dim : in integer;
   barray : in out kdelemptr_a-raytype;
   ncount : in out integer) is

   -- Procedure name: AssessCandidate
   -- Purpose: Determine the pair of bucket entries which produces
   -- the minimal mean distortion when merged
   -- Input arguments:
   --   elem - pointer to the KD tree bucket under evaluation
   --   barray - array of pointer to all buckets in the KD tree
   --   ncount - counter initialized to zero
   -- Output arguments:
   --   barray - array of pointers to all buckets that can be merged
   --   ncount - counter used to keep track of the total number
   --   of buckets that can be merged

   ientry, jentry : kdeentry_ptr_type;
   reduction, dotprd, diff : float;
   firsttime : integer;

begin

   firsttime := TRUEE;

   if (elem.bucket.count > 1) then
      ientry := elem.bucket.lists_array(0);
      for i in 0 .. elem.bucket.count - 1 loop
         jentry := ientry.next_array(0);
         for j in i + 1 .. elem.bucket.count - 1 loop
            dotprd := 0.0;
            for k in 0 .. dim - 1 loop
               diff := ientry.mean_array(k) - jentry.mean_array(k);
               dotprd := dotprd + diff * diff;
            end loop;
            reduction := (dotprd * ientry.weight * jentry.weight) /
                         (ientry.weight + jentry.weight);
            if ((reduction < elem.bucket.distort) or
                 (firsttime = TRUEE)) then
               elem.bucket.distort := reduction;
               elem.bucket.entiya := ientry;
               elem.bucket.entiyb := jentry;
               firsttime := FALSEE;
            end if;
            jentry := jentry.next_array(0);
         end loop;
      end loop;
      ientry := ientry.next_array(0);
   end loop;
   barray(ncount) := elem;
   ncount := ncount + 1;
end if;
end AssessCandidate;
separate (MergeDown Pkg)

procedure BalanceKDtree (tree : in kdtree_ptr_type;
                        bcktarray : in out kdelem_ptr_array_type) is

-- Procedure name: BalanceKDtree

-- Purpose: Redistribute the entries in a KD tree so that each bucket
--          has approximately the same number of entries

-- Input arguments:
--    tree - pointer to a KD tree

-- Output arguments:
--    bcktarray - array used to retain a pointer to each bucket after
--                balancing

bptr : integer;
mean : mean_array_type(0 .. dim - 1) := (others => 0.0);
wvar : wvar_array_type(0 .. dim - 1) := (others => 0.0);

begin
    if (tree.root.typee = KDNODEE) then
        CollapseKDnode(tree.root, tree.dim, tree.nbuckets);
    end if;

    bcktarray(0) := tree.root;
bptr := 1;

    SplitBucket(tree.root, tree.dim, tree.nbuckets, bcktarray,
                bptr, mean, wvar);

end BalanceKDtree;
separate (MergeDown_Pkg)
function BucketCompare (one : Kdelem_ptr_type; two : kdelem_ptr_type)
return boolean is

begin
  if one.bucket.distort < two.bucket.distort then
    return FALSE;
  else
    return TRUE;
  end if;
end BucketCompare;
separate (MergeDown_Pkg)

procedure CollapseKDNode (elem : in out ktdelem_ptr_type;
   dim : in integer;
   betr : in out integer) is

   FIRSTIME : BOOLEAN := TRUE;
   ptr,entptr, lentry, rentry, testentry: kdentry_ptr_type;
   bucket : ktdelem_ptr_type;

begin

   if elem.node.lower.typee /= KDBUCKETT then
      CollapseKDNode (elem.node.lower, dim, betr);
   end if;

   if elem.node.upper.typee /= KDBUCKETT then
      CollapseKDNode (elem.node.upper, dim, betr);
   end if;

   bucket := elem.node.lower;

   for i in 0 .. dim - 1 loop
      entptr := elem.node.lower.bucket.lists_array(i);
      lentry := elem.node.lower.bucket.lists_array(i);
      rentry := elem.node.upper.bucket.lists_array(i);
      testentry := elem.node.upper.bucket.lists_array(1);

      while (lentry /= null) and (rentry /= null) loop
         if lentry.mean_array(i) < rentry.mean_array(i) then
            if (FIRSTIME = TRUE) then
               elem.node.lower.bucket.lists_array(i) := lentry;
               entptr := lentry;
               FIRSTIME := FALSE;
            else
               -- FIRSTIME = FALSE
               entptr.next_array(i) := lentry;
               entptr := lentry;
            end if;
            lentry := lentry.next_array(i);
         else
            -- case where lentry.mean_array(i) >
            rentry := rentry.next_array(i);
         end if;
      end if;
   end if;
end if;

end loop;

if (lentry /= null) then
    while (lentry /= null) loop
        entptr.next_array(i) := lentry;
        entptr := lentry;
        lentry := lentry.next_array(i);
    end loop;
end if;

if (rentry /= null) then
    while (rentry /= null) loop
        entptr.next_array(i) := rentry;
        entptr := rentry;
        rentry := rentry.next_array(i);
    end loop;
end if;

FIRSTIME := TRUE;
end loop;

bucket.bucket.count := elem.node.lower.bucket.count +
                    elem.node.upper.bucket.count;

DestroyKDbucket (elem.node.upper);
DestroyKDnode (elem);

bctr := bctr - 1;
elem := bucket;

end CollapseKDNODE;
separate (MergeDown_Pkg)

procedure CompressKDtree (tree : in kdtree_ptr_type; nmerge : in integer;
bcktarray : in out kdelem_ptr_array_type) is

begin

ncount := 0;
for i in 0 .. tree.nbuckets - 1 loop
   AssessCandidate(bcktarray(i), tree.dim, bcktarray, ncount);
end loop;
if (nmerge > ncount) then
   nmerge_temp := ncount;
end if;
if (ncount > 1) then
   Quicksort(bcktarray(0 .. ncount-1));
end if;
for i in 0 .. nmerge_temp - 1 loop
   ReduceKDbucket(bcktarray(i), tree.dim);
end loop;
tree.nentries := tree.nentries - nmerge_temp;
end CompressKDtree;
function CreateKDnode  return kdelem_ptr_type is

-- Function name: CreateKDnode
-- Purpose: Create a KD tree node
-- Input arguments:
-- none
-- Returns:
-- pointer to the newly created KD tree node

node : kdelem_ptr_type;

begin
  node := new kdelem(kdnode_type);
  node.typee := KDNODEE;
  return node;

end CreateKDnode;
procedure GetBucketStats (elem in kdelem_ptr_type;
    dim in integer;
    mean in out mean_array_type;
    wvar in out wvar_array_type) is

    entryy : kentry_ptr_type;
    wgtsum : float;

    begin

    wgtsum := 0.0;

    for i in 0 .. dim - 1 loop
        mean(i) := 0.0;
        wvar(i) := 0.0;
    end loop;

    entryy := elem.bucket.lists_array(0);
    while (entryy /= null) loop
        wgtsum := wgtsum + entryy.weight;
        for i in 0 .. dim - 1 loop
            mean(i) := mean(i) + entryy.wmean_array(i);
            wvar(i) := wvar(i) + entryy.wsqmn_array(i);
        end loop;

        entryy := entryy.next_array(0);
    end loop;

    for i in 0 .. dim - 1 loop
        mean(i) := mean(i) / wgtsum;
        wvar(i) := (wvar(i) / wgtsum) - (mean(i) * mean(i));
    end loop;

    end GetBucketStats;
separate (Mergedown_Pkg)
procedure MergeDownKDtree (tree : in kdtree_ptr_type;
ncntrds : in integer) is

-- Procedure name: MergeDownKDtree

-- Purpose: Reduce a KD tree to a single bucket having ncntrds
-- entries using the PNN algorithm

-- Input arguments:
--    tree - pointer to a KD tree
--    ncntrds - desired number of entries after merging

-- Output arguments:
--    None

-- Returns:
--    Nothing

ptr : kdelem_ptr_type;
nmerge, ntile : integer;
maxbkts : integer := tree.nentries / (BUCKETSIZE / 2);
bcktarray : kdelem_ptr_array_type(0 .. maxbkts);

begin

while (tree.nentries > ncntrds) loop

BalanceKDtree (tree, bcktarray);

if KDMERGE * float(tree.nbuckets) > 1.0 then

-- truncate by the integer conversion by subtracting .5
ntile := integer((KDMERGE * float(tree.nbuckets)) - 0.5);

else

ntile := 1;
end if;

if (tree.nentries - ncntrds) < ntile then

nmerge := tree.nentries - ncntrds;
else

nmerge := ntile;
end if;

CompressKDtree (tree, nmerge, bcktarray);
end loop;

if tree.root.typee = KDNODEE then

CollapseKDnode (tree.root, tree.dim, tree.nbuckets);
end if;

end MergeDownKDtree;
procedure Quicksort (bcktarray : in out kdelem_ptr_array_type) is

   SIZE : INTEGER := bcktarray'length;
   FIRST : INTEGER := bcktarray'FIRST;
   LAST : INTEGER := bcktarray'LAST;
   P : INTEGER;

procedure SWAP(A, B : in out KDELEM_PTR_TYPE) is

   TEMP : KDELEM_PTR_TYPE;

begin

   TEMP := A;
   A := B;
   B := TEMP;

end SWAP;

procedure PARTITION(bcktarray : in out KDELEM_PTR_ARRAY_TYPE;
   NEWPIVOT : out INTEGER) is

   PIVOTVALUE : KDELEM_PTR_TYPE;
   FIRST : INTEGER := bcktarray'FIRST;
   LAST : INTEGER := bcktarray'LAST;
   LOWER : INTEGER;
   UPPER : INTEGER;
   LASTOPEN : INTEGER;

begin

   LOWER := FIRST;
   UPPER := LAST;
   PIVOTVALUE := bcktarray(FIRST);
   LASTOPEN := FIRST;

   while LOWER < UPPER loop
      while UPPER > LOWER and then
         BucketCompare(bcktarray(upper), PIVOTVALUE) loop

         UPPSR := UPPER - 1;
      end loop; 

      bcktarray(LASTOPEN) := bcktarray(UPPER);
      LASTOPEN := UPPER;

      while LOWER < UPPER and then
         BucketCompare(PIVOTVALUE, bcktarray(lower)) loop

         LOWER := LOWER + 1;
      end loop;

      bcktarray(LASTOPEN) := bcktarray(LOWER);
      LASTOPEN := LOWER;
   end loop;

end PARTITION;
end loop;

bcktarray(LASTOPEN) := PIVOTVALUE;
NEWPIVOT := LASTOPEN;
end PARTITION;

begin -- QUICKSORT

if SIZE <= 1 then
  null;
else
  PARTITION(bcktarray,P);
  QUICKSORT(bcktarray(FIRST .. P - 1));
  QUICKSORT(bcktarray(P + 1 .. LAST));
end if;
end Quicksort;
with Data_Struct_Pkg; use Data_Struct_Pkg;
separate (MergeDown_Pkg)
procedure ReduceKDbucket (elem : in kdelem_ptr_type;
dim : in integer) is

-- Procedure name: ReduceKDbucket
-- Purpose: Merges a pair of bucket entries into a single entry
-- Input arguments:
--   elem - pointer to the KD tree bucket whose entries are to
--          be merged
--   dim - dimension of the data within the entries
-- Output arguments:
--   None

last_entry, ientry, jentry, leptr, oldptr : kdentry_ptr_type;
newweight : float;
rmcnt : integer;
REMOVE FIRST ENTRY : BOOLEAN := TRUE;
FIRST ENTRY : BOOLEAN := TRUE;
ptr, TEST_PTR : kdentry_ptr_type;

begin

ientry := elem.bucket.entrya;
jentry := elem.bucket.entryb;

-- remove ientry and jentry from the list
for i in 0 .. dim - 1 loop
    leptr := elem.bucket.lists_array(i);
    rmcnt := 0;
    while rmcnt < 2 loop
        if ((leptr /= ientry) and (leptr /= jentry)) then
            last_entry := leptr;
            leptr := leptr.next_array(i);
            REMOVE FIRST ENTRY := FALSE;
        else
            if REMOVE FIRST ENTRY = TRUE then
                elem.bucket.lists_array(i) := leptr.next_array(i);
            else
                last_entry.next_array(i) := leptr.next_array(i);
            end if;
            leptr := leptr.next_array(i);
            rmcnt := rmcnt + 1;
        end if;
    end loop;
    REMOVE FIRST ENTRY := TRUE;
end loop;

newweight := ientry.weight + jentry.weight;
for i in 0..dim-1 loop
  ientry.mean_array(i) := (ientry.mean_array(i) * ientry.weight + jentry.mean_array(i) * jentry.weight) / newweight;
  
  ientry.wmean_array(i) := ientry.mean_array(i) * newweight;
  ientry.wsqmn_array(i) := ientry.mean_array(i) * ientry.wmean_array(i);
end loop;

ientry.weight := newweight;

-- Reinsert ientry into the list in the proper order

for i in 0..dim-1 loop
  leptr := elem.bucket.lists_array(i);
  -- traverse entries that will remain unchanged in original list
  while (leptr /= null) and then (leptr.mean_array(i) < ientry.mean_array(i)) loop
    oldptr := leptr;
    leptr := leptr.next_array(i);
    FIRST_ENTRY := FALSE;
  end loop;

  -- insert ientry
  if (FIRST_ENTRY = TRUE) then
    elem.bucket.lists_array(i) := ientry;
  else
    oldptr.next_array(i) := ientry;
  end if;

  ientry.next_array(i) := leptr;
  FIRST_ENTRY := TRUE;
end loop;

elem.bucket.count := elem.bucket.count - 1;

DestroyKDentry(jentry);

end ReduceKDbucket;
with Build Pkg; use Build_Pkg; -- to "see" CreateKDbucket separate (MergeDown_Pkg)
procedure SplitBucket (oldbucket : in out kdelem_ptr_type;
    dim : in integer;
    bcptr : in out integer;
    bcktarray : in out kdelem_ptr_array_type;
    bptr : in out integer;
    mean : in out mean_array_type;
    wvar : in out wvar_array_type) is

-- -----------------------------------------------
-- Procedure name: Splitbucket
-- Purpose: Recursive procedure used to split a bucket into two
-- smaller buckets having half as many entries
-- -----------------------------------------------

j, bcount, medindx : integer;
newnode : kdelem_ptr_type;
newbucket : kdelem_ptr_type;
dummy : kdelem_ptr_type;
oldptr, newptr : kdentry_ptr_type;
entryy : kdentry_ptr_type;
FIRSTIME_LEFT : BOOLEAN := TRUE;
FIRSTIME_RIGHT : BOOLEAN := TRUE;

begin

if (oldbucket.bucket.count > BUCKETSIZE) then

    GetBucketStats (oldbucket, dim, mean, wvar);

    -- find dimension with largest variance
    j := 0;
    for i in 1 .. dim - 1 loop
        if (wvar(i) > wvar(j)) then
            j := i; -- j is dimension with largest variance
        end if;
    end loop;

    bcount := oldbucket.bucket.count; -- bcount is BUCKETCOUNT
    medindx := (bcount + 1) / 2; -- median index
    newnode := CreateKDnode;
    newnode.node.dindx := j; -- dimension to be split
    newbucket := CreateKDbucket(dim);
    newnode.node.lower := oldbucket;
    newnode.node.upper := newbucket;
    bcptr := bcptr + 1; -- increment number of buckets in tree

end if;

end SplitBucket;
bcktarray(bptr) := newbucket;

bptr := bptr + 1; -- increment array index of bcktarray

-- traverse the entries below the median value in the
-- j dimension (the dimension with the largest variance)
-- and set entryy.splitleft = TRUE

entryy := oldbucket.bucket.lists_array(j);
for i in 0 .. medindx - 1 loop
    entryy.splitleft := TRUE;
    entryy := entryy.next_array(j);
end loop;

-- traverse the entries above the median value in the
-- j dimension (the dimension with the largest variance)
-- and set entryy.splitleft = FALSE

for i in medindx .. bcount - 1 loop
    entryy.splitleft := FALSE;
    entryy := entryy.next_array(j);
end loop;

oldbucket.bucket.count := medindx;
newbucket.bucket.count := bcount - medindx;

for i in 0 .. dim - 1 loop
    oldptr := oldbucket.bucket.lists_array(i);
    newptr := newbucket.bucket.lists_array(i);
    entryy := oldbucket.bucket.lists_array(i);

    while (entryy /= null) loop
        if (entryy.splitleft = TRUE and
            FIRSTTIME_LEFT = TRUE) then
            oldbucket.bucket.lists_array(i) := entryy;
            oldptr := entryy;
            FIRSTTIME_LEFT := FALSE;

        elsif (entryy.splitleft = TRUE and
            FIRSTTIME_LEFT = FALSE) then
            oldptr.next_array(i) := entryy;
            oldptr := entryy;

        elsif (entryy.splitleft = FALSE and
            FIRSTTIME_RIGHT = TRUE) then
            newbucket.bucket.lists_array(i) := entryy;
            newptr := entryy;
            FIRSTTIME_RIGHT := FALSE;

        elsif (entryy.splitleft = FALSE and
            FIRSTTIME_RIGHT = FALSE) then
            newptr.next_array(i) := entryy;
            newptr := entryy;
        end if;
    end while;

    entryy := entryy.next_array(i);
end loop;

end if;
entryy := entryy.next_array(i);
end loop;

FIRSTTIME_LEFT := TRUE;
FIRSTTIME_RIGHT := TRUE;

oldptr.next_array(i) := null;
newptr.next_array(i) := null;
end loop;

SplitBucket(newnode.node.lower, dim, bctr, bcktarray, bptr, mean, vvar);

oldbucket := newnode;
end if;
end SplitBucket;
with Data_Struct_Pkg; use Data_Struct_Pkg;
with UNCHECKED_DEALLOCATION;
package Destroy_Pkg is

-- This package specification contains the dynamic deallocation
-- routines which are to be visible

procedure DestroyKDnode (node : in out Kdelem_ptr_type);

procedure DestroyKDtree (tree : in out Kdtreeptr_type);

procedure DestroyKDbucket (bucket : in out kdelemn_ptr_type);

procedure DestroyKDentry (entryy : in out kdentry_ptr_type);

end Destroy_Pkg;
package body Destroy_Pkg is

-- This package body contains the routines for deallocated memory which was previously dynamically allocated.

procedure DestroyKDnode (node : in out kdelem_ptr_type) is separate;

procedure DestroyKDentry (entryy : in out kdentry_ptr_type) is separate;

procedure DestroyKDbucket (bucket : in out kdelem_ptr_type) is separate;

procedure DestroyLastBucket (bucket : in out kdelem_ptr_type) is separate;

procedure DestroyKDtree (tree : in out kdtree_ptr_type) is separate;

end Destroy_Pkg;
separate (Destroy_Pkg)
procedure DestroyKDbucket (bucket : in out Kdelem_ptr_type) is

-- ------------------------------------------------------------------
-- Procedure name: DestroyKDbucket
-- Purpose: Destroy a Kd tree bucket
-- Input arguments:
--   bucket - bucket to be destroyed
-- Output arguments:
--   bucket - bucket is null upon successful execution
--     of FREE(bucket)
-- ------------------------------------------------------------------

procedure FREE is new UNCHECKED_DEALLOCATION(kdelem,
                         kdelem_ptr_type);
begin
  FREE(bucket);
end DestroyKDbucket;
separate (Destroy_Pkg)
procedure DestroyKDentry (entryy : in out Kdentry_ptr_type) is

-- Procedure name: DestroyKDentry
-- Purpose: Destroy a KD tree bucket entry
-- Input arguments:
-- entryy - pointer to the entryy to be destroyed
-- Output arguments:
-- entryy - points to null upon successful execution of
--           FREE(entryy)

procedure FREE is new UNCHECKED_DEALLOCATION (Kdentry,
                                            Kdentry_ptr_type);

begin
   FREE(entryy);
end DestroyKDentry;
separate (Destroy_Pkg)
procedure DestroyLastBucket (bucket : in out Kdelem_ptr_type) is

-- -----------------------------------------------------------------------------
--
-- Procedure name : DestroyLastBucket
--
-- Purpose : Destroy the last bucket in a tree
--
-- Input arguments:
--   bucket - bucket to be destroyed
--
-- Output arguments:
--   None
--
-- -----------------------------------------------------------------------------

entryy, next : kdentry_ptr_type;

begin

  entryy := bucket.bucket.lists_array(0);
  while entryy /= null loop
    next := entryy.next_array(0);
    DestroyKDentry (entryy);
    entryy := next;
  end loop;

  DestroyKDbucket(bucket);

end DestroyLastBucket;
separate (Destroy Pkg)
procedure DestroyKDnode (node : in out Kdelem_ptr_type) is

-- -----------------------------------------------
-- Procedure name: DestroyKDnode
--
-- Purpose:
--   Deallocate a KD tree node
--
-- Input arguments:
--   node - pointer to the entry to be destroyed
--
-- Output arguments:
--   node - point to null upon successful execution of FREE(node)
--
-- -----------------------------------------------

procedure FREE is new UNCHECKED_DEALLOCATION(kdelem,
   kdelem_ptr_type);

begin

FREE(node);

end DestroyKDnode;
separate (Destroy_Pkg)
procedure DestroyKDtree (tree : in out kdtree_ptr_type) is

-- --------------------------------------------------------------------
--
-- Procedure name: DestroyKDtree
--
-- Purpose: Deallocate a KD tree structure
--
-- Input arguments:
--    tree - pointer to the KD tree
--
-- Output arguments:
--    tree - pointer to null upon successful completion of
--           FREE(tree)
--
-- --------------------------------------------------------------------

    procedure FREE is new UNCHECKED_DEALLOCATION(kdtree,
                                                kdtree_ptr_type);

begin

    if tree.root /= null then
        DestroyLastBucket(tree.root);
    end if;

    FREE(tree);

end DestroyKDtree;
package timer is

-- See bottom for comments on how to use the timer

---

type microsec_timer is private;

procedure init_timer( obj : out microsec_timer );

function elapsed_time( obj : in microsec_timer ) return integer;

function identity( arg : integer ) return integer;

function always_true return boolean;

private

type microsec_timer is new integer;

end timer;

-- Calling sequence: Call the subprograms in this order:

---

loop_count : constant integer := 100; -- say...

; 

dummy_timer : timer.microsec_timer;

dummy_elapsed_time : integer;

dummy_arg : integer;

my_timer : timer.microsec_timer;

my_elapsed_time : integer;

;

begin

.

now loop through dummy loop to determine the length

of time it takes to run through the loop itself.

We will subtract this out later.

.

timer.init_timer( dummy_timer );

for i in 1..loop_count loop

  dummy_arg := timer.identity( dummy_arg );

end loop;

if timer.always_true then

  dummy_elapsed_time := timer.elapsed_time( dummy_timer );

end if;

.

-- now run through the same loop and add the actual code that

-- you want to time.

.

timer.init_timer( my_timer );

for i in 1..loop_count loop

  -- do something here that needs timing...

  timer.identity( dummy_arg );


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end loop;
if timer.always_true
    my_elapsed_time := timer.elapsed_time( my_timer );
end if;

-- now subtract off the dummy loop time and divide by the
-- number of times that the loop occurs. This equals one
-- iteration of the interesting code.

    time_for_one_iteration :=
        ( my_elapsed_time - dummy_elapsed_time ) / loop_count );

-- note that the value of my_timer is not changed by a call to
-- timer.elapsed_time. You can have as many timers as you wish.
with system; use system;
with condition_handling; use condition_handling;
with starlet; use starlet;

package body timer is

-- Package: timer
--
-- Description: This package provides two subprograms which are called
to time operations in the VMS environment.
--
-- References: Please see the VAX/VMS System Services Reference Manual
under the $GETJPI system service description.
--
-- Revision history: S. French 25-Jan-1989
--
-- Host processor: VAX/VMS 4.7
--
-- Package dependencies: This package interfaces with the VMS system
service $GETJPI to get the cpu time.
--

function cpu_time_clock return integer is
  cputim : integer;
  pragma volatile (cputim);
  jpi_status : cond_value_type;
  jpi_item_list : constant item_list_type :=
    ( (4, jpi_cputim, cputim'address, address_zero),
      (0, 0, address_zero, address_zero) );
begin
  -- call getjpi to set cputim to total accumulated cpu time
  -- (in millisecond tics)
  getjpi ( status => jpi_status, itmlst => jpi_item_list );
  return (cputim * 10);
end cpu_time_clock;

procedure init_timer( obj : out microsec_timer ) is
begin
  obj := microsec_timer( cpu_time_clock );
end init_timer;

function elapsed_time( obj : in microsec_timer ) return integer is
begin
  return cpu_time_clock - integer( obj );
end elapsed_time;

function identity( arg : integer ) return integer is
  some_value : integer := 0;
begin
  some_value := some_value + arg;
  return some_value;
end identity;
function always_true return boolean is
  bool_value : Boolean := true;
begin
  return bool_value;
end always_true;

begin
  null;
end timer;
package timer is

-- See bottom for comments on how to use the timer
-- --------------------------------------------------

type microsec_timer is private;

procedure init_timer( obj : out microsec_timer );

function elapsed_time( obj : in microsec_timer ) return integer;

function identity( arg : integer ) return integer;

function always_true return boolean;

private

  type microsec_timer is new integer;

end timer;

-- --------------------------------------------------

-- Package: timer

-- Description: This package provides two subprograms which are called
to time operations.

-- Calling sequence: Call the subprograms in this order:

  loop_count : constant integer := 100; -- say...
  dummy_timer : timer.microsec_timer;
  dummy_elapsed_time : integer;
  dummy_arg : integer;
  my_timer : timer.microsec_timer;
  my_elapsed_time : integer;

begin

  now loop through dummy loop to determine the length of time
  it takes to run through the loop itself. We will subtract
  this out later.

  timer.init_timer( dummy_timer );

  for i in 1..loop_count loop
    dummy_arg := timer.identity( dummy_arg );
  end loop;

  if timer.always_true then
    dummy_elapsed_time := timer.elapsed_time( dummy_timer );
  end if;

  now run through the same loop and add the actual code that
  you want to time.
  
  timer.init_timer( my_timer );
for i in 1..loop_count loop
    do something here that needs timing...
    timer.identity( dummy_arg );
end loop;

if timer.always true then
    my_elapsed_time := timer.elapsed_time( my_timer );
end if;

now subtract off the dummy loop time and divide by the
number of times that the loop occurs. This equals one
iteration of the interesting code.

time_for_one_iteration :=
    ( my_elapsed_time - dummy_elapsed_time ) / loop_count );

note that the value of my_timer is not changed by a call to
timer.elapsed_time. You can have as many timers as you wish.
Revision history: S. French 25-Jan-1989
package body timer is

-- Package: timer
-- -----
-- Description: This package provides two subprograms which are called
to time functions in the unix environment. This timer was used to
perform timing on the MIPS Magnum 3000 computer system.
-- -----
-- References: Please see the man page clock for information about how
the unix time is obtained.
-- -----
-- Revision history:  S. French 25-Jan-1989
-- -----
-- Host processor: gppe gppe 3_10 UMIPS mips m120-5 ATT_V3_0
-- -----
-- Package dependencies: This package interfaces with the UNIX system
call "clock".
-- ----------------------------------

function unix_clock return integer;
pragma INTERFACE(C, unix_clock);
pragma INTERFACENAME(unix_clock,"clock");

procedure init_timer( obj : out microsectimer ) is
begin
    obj := microsec_timer( unix_clock );
end init_timer;

function elapsed_time( obj : in microsec_timer ) return integer is
begin
    return unix_clock - integer( obj );
end elapsed_time;

function identity( arg : integer ) return integer is
    some_value : integer := 0;
begin
    some_value := some_value + arg;
    return some_value;
end identity;

function always_true return boolean is
    bool_value : boolean := true;
begin
    return bool_value;
end always_true;

begin
    null;
end timer;

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with text_io; use text_io;
with data_struct_pkg; use data_struct_pkg;
procedure READ_DATA (INFILE : IN OUT FILE_TYPE;
    positions : out means_array_type;
    weights : out weights_array_type) is

-- Procedure Name: READ_DATA

-- Purpose: Procedure READ_DATA is called by Procedure Main
to read in the input data file.

i : integer := 0;
j : integer := 0;
package FLOAT_IO is new TEXT_IO.FLOAT_IO(FLOAT);

begin

while not END OF FILE(INFILE) loop
    FLOAT_IO.GET(INFILE, positions(i));
    i := i + 1;
    FLOAT_IO.GET(INFILE, positions(i));
    i := i + 1;
    FLOAT_IO.GET(INFILE, weights(j));
    j := j + 1;
    SKIP_LINE(INFILE);
end loop;

CLOSE(INFILE);

end READ_DATA;