An Empirical Performance Comparison of Some Variations of the \textit{k-d} Tree and \textit{BD} Tree

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Database applications very often require a sophisticated class of storage structures in order to answer different types of queries efficiently. This often dictates that the file should be organized on multiple keys. Several storage structures have been proposed to satisfy these needs. Most of these are a generalization of the storage structures used for managing one-dimensional data. The \textit{k-d} tree is one such example and it is a natural generalization of the standard one-dimensional binary search tree. Recently, a new storage structure, called the \textit{BD} tree, was proposed to manage multidimensional data. This structure has good dynamic characteristics. Several variations are possible on the basic \textit{k-d} tree structure. This paper studies the performance implications of three variations. Further, it provides an empirical performance comparison of the \textit{k-d} tree and \textit{BD} tree in database applications.

\textbf{KEY WORDS}: Multidimensional data structures; databases; partial match query; range query; multikey searching.

1. \textbf{INTRODUCTION}

Database systems are becoming increasingly popular as the volume of data that these systems must handle is expanding rapidly. It is now imperative that these database systems should use more efficient storage structures than the traditional ones like indexed sequential files. These traditional

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storage structures are efficient in answering queries which specify all key
codes in the record—queries commonly referred to as “exact match”
queries. However, an information system must be capable of responding
efficiently to various types of queries. Rivest\(^\text{(1)}\) classified the queries in a
database environment into several categories. As far as this paper is con-
cerned, we are interested in the following three types of queries.

(a) **Exact match query**: This is the simplest type of query and
specifies a value for each key in the record.

(b) **Partial match query**: Assuming that each record contains \(k\) keys,
then a partial match query specifies \(s\) key values, \(s < k\), that must
be matched. The remaining \(k - s\) keys are left unspecified.

(c) **Range query**: These are the same as exact match queries except
that a range of required values rather than a single value may be
specified for each key.

In a way, the first two types of queries can be considered as a subset of the
range queries. For example, in an exact-match query, the range of all
attributes can be thought of as one (some specified value). Similarly, we
can consider the range of those attributes that are not specified in a partial
match query to be \(-\infty\) to \(+\infty\). Here \(+\infty\) indicates the maximum possible
value for the attribute and \(-\infty\) indicates the minimum possible value.

The traditional storage structures are not efficient in answering dif-
ferent types of queries and, therefore, most database applications now
require a more sophisticated class of storage structures—called multikey
storage structures. As a result of this need and interest, several new mul-
tikey access storage structures have been reported in the literature. Bentley
and Shamos\(^\text{2}\) consider the problem of ranking a point in a multidimen-
sional space. They developed a data structure, called ECDF tree, to solve
this problem in \(O(N \cdot (\log N)^k)\) time using \(O(N \cdot (\log N)^{k-1})\) space.
Bentley\(^\text{3}\) has investigated a number of searching problems defined on sets
of points in \(k\)-dimensional space. It should be noted that achieving a lower
bound for range queries (see Ref. 4) requires excessive amounts of storage.
Some efficient worst-case data structures have been reported in Ref. 5. Since
exact match and partial match queries can be considered as a subset of
range queries, several data structures have been proposed to handle range
queries efficiently (see Refs. 6 and 7). Some of these highly “efficient” data
structures like quintary trees\(^\text{8}\) provide a very good response time.
However, these structures are not suitable for most applications because of
their huge storage requirement. There are several other storage structures
that are more generally suitable for implementation because they provide a
reasonable compromise between the storage cost and response time. These