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Integrating Run Length Encoding and Column oriented database execution using Binary Search Tree

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Abstract:Column oriented databases have attracted significant amount of attention recently and database systems based on Column oriented technology are used extensively for analytical processing such as those found in data warehouses, decision support, and business intelligence and forecasting applications. Column oriented databases have enormous potential for data compression because of the similarity of adjacent records.
This paper will discuss an algorithm that makes use of this similarity in a column oriented databases to integrate the compression and execution processes. It proposes a new indexing method called Binary Search Tree (BST) indexing that supports O (log n) insertion, deletion and look-up operations. Additionally, the paper also describes the implementation of these basic operations.

Keywords:Column-oriented database, Run-length encoding, Compression, Binary Search Tree, Performance

I. INTRODUCTION

Column oriented databases are receiving increased attention these days and are used increasingly in analytical and data warehousing applications. This is due to the fact that vertical partitioning of the relation makes faster reads and aggregation possible. In addition, various compression methods like run length encoding and bitmap encoding help to achieve a higher compression ratio in column oriented databases. The performance depends on the level of compression achieved. [1] shows that run length encoding and bitmap encoding schemes are dependent on the ordering of the tuples. Hence out of order insertions typically degrade the compression achieved and consequently the performance of the look-ups.
On average, the time taken to insert or delete a tuple from a relation varies linearly with the number of tuples in a relation. This is because, in addition to the updated tuple, the storage keys or identifiers of the successive tuples have to be updated as well. In addition, the tuples in a read optimized relation need to be decompressed and recompressed after an update operation. This requires additional time. This paper shows that it is possible to perform in-place inserts, deletes and updates in sub-linear time in the number of tuples in the relation by making use of Binary Search Trees.
Each node in the Binary Search Tree (BST) contains the value of the attribute and each of these points to a linked list which holds the databases indices, where the attribute is stored. The compression ratio is further improved because the database indices of the tuples are stored along with the tuple attributes.
Run-length Encoding Scheme- In column-oriented databases, every attribute in a tuple is stored separately as a sequence of values. These sequences could be run-length encoded or bitmap encoded. The run-length encoding scheme compresses successive repetitions of values or runs in a sequence. There are two ways of representing a successive repetition of values or runs in sequence [2] – count based and offset based representation. Consider the sequence of values 10(1062), 6(1063), 9(1064), 9(1065), 10(1066), 10(1067), 4(1068), 4(1069), 4(1070), 6(1071), 6(1072), 14(1073), 14(1074). The integers in the brackets (starting from 1062) represent the database indices associated with the tuples of which, the attributes are a part. If we use the count based representation of runs to encode this sequence, we

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would get (10,1), (6,1), (9,2), (10,2), (4,3), (6,2), (14,2) as the result. Instead if we use offset based representation, we would get (10,1), (6,2), (9,4), (10,6), (4,9), (6,11), (14,13).

The organization of this paper is described as below.

1. Section II lists down the related works that were referred in this journal.
2. Section III.A defines BST indices and explains how a BST index is created for the example sequence shown above.
3. Section III.B explains how the basic operation like look-up, insertion, deletion, and updating is carried out on a BST index.

II. BACKGROUND AND RELATED WORKS

A. Database Compression

Database compression is an effective way of saving space and reducing disk I/O. Many compression schemes have been devised based on character encoding or detection of repetitive strings.

Dictionary coding [2] is a compression technique that uses character encoding to compress the data. All the distinct values are written into the dictionary, and they are encoded as tokens that act as their indexes in the data dictionary. These tokens occupy less space than the data, and replace all their occurrences, which results in compression. For example, if an attribute that consumes 5 bytes of space has only 8 distinct values, they can be replaced by tokens, each of 3 bits in length. Decompression involves only searching the dictionary for the data using its token as an index, so it has a very high decompressing performance.

Run-length encoding (RLE) [3] is a simple form of data compression that converts the runs of data (the sequences in which same value occurs consecutively) into a (value, length) pair. The pair (v, n) denotes that the value 'v' has repeated consecutively for 'n' number of times. For example, consider the sequence: a,a,a,a,b,b,b,a,a,b,b,b,b. This sequence can be compressed as: (a,4),(b,3),(a,2),(b,4) using RLE technique. The performance of this compression method depends on the length of the run. Longer the run, higher will be the compression ratio.

Besides the ones mentioned above, there are other compression approaches used in real systems such as null suppression, delta coding, bit packing [2][4], et al.

B. Row-oriented storage, Column-oriented storage, Compression

Traditional databases use row-oriented storage, in which an entire record is stored as a single entity. A relatively new approach is the column-oriented storage [5], where all the values of a column are stored together, instead of records. Both the approaches have their own benefits and limitations. For example, if a record has to be inserted or deleted from the table, the row-oriented database can achieve it within a single disk seek, while column-oriented database requires multiple disk seeks, as the columns of a record are stored separately. On the other hand, if an aggregate has to be computed, only the required column needs to be accessed, instead of the entire record. So, row-oriented database is suitable for transaction processing, whereas column-oriented database performs better in analytics.

Data compression plays a cardinal role in query processing, as it reduces disk I/O. The adjacent columns of a record may have different value domains. When these values are stored together as in row-oriented storage, value locality on the page becomes very poor. So, row-oriented storage has only a little potential for compression. On the contrary, as the column data is of uniform type, and same values can occur repeatedly, column-oriented data is more compressible than its counterpart. As a result, performance optimization of the column-store in transactional operations, and new encoding schemes for compression has become areas of active research.

A notable contribution in columnar compression and execution is given by [3]. It proposes an indexing scheme called *count indexes* that supports in-place insertions, deletions, updates and look ups on a run-length encoded sequence with n runs in time that is sub-linear in the number of tuples. This is achieved by maintaining the count index as a binary tree, where (value, length) pairs of the sequence form the leaf nodes, and the interior nodes store the sum of the 'length' of their children. Thus, the root node stores the total number of elements in the sequence.

In this paper, we present a new indexing scheme called Binary Search Tree (BST) indexing, which also makes use of run-length encoding (RLE) technique. Representing the sequence as a binary search tree makes it possible to carry out all the operations – insert, update and delete, in O(log n) time for n runs.

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Vol. 2, Issue 9, September 2013

III. BINARY SEARCH TREE INDEX

A. Definition

A BST index on a sequence of integers along with their database indices is defined as a binary search tree structure which contains the integers in its nodes. The database indices are maintained as linked lists for each node of the main tree. The sample BST index structure for the sequence of integers mentioned in the introductory section is shown below.

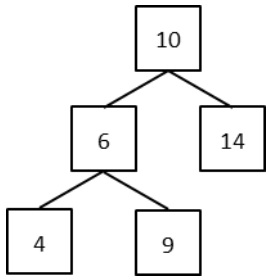
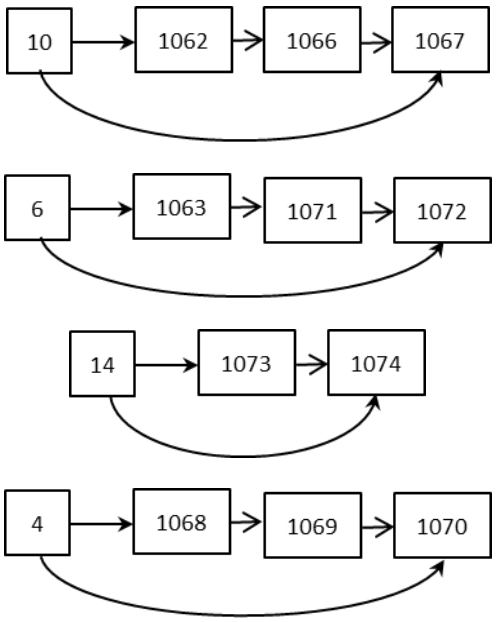


Fig. 1 BST Index structure for thegiven sequence of integers

The content of a single node in the BST is as follows.

1. Attribute value (value)
2. Pointer to right child (right_child)
3. Pointer to left child (left_child)
4. Pointer to first node of linked list (first)
5. Pointer to last node of linked list (last)

The linked list structures for the nodes of the BST are shown below.



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Vol. 2, Issue 9, September 2013

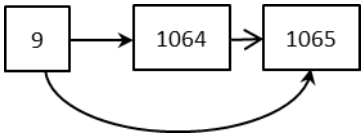

Fig. 2 Linked List structure for the BST nodes in fig. 1.

B. Basic Operations

1) Insertion:

The insertion to the BST index works the same way as insertion to the binary search tree. When an element is to be inserted, it is compared with the node attributes. If the element is greater than the node element, the tree is traversed right; otherwise the tree is traversed left. For e.g., insertion of the element 16 with a database index 1075 in the tree will result in the following tree structure.

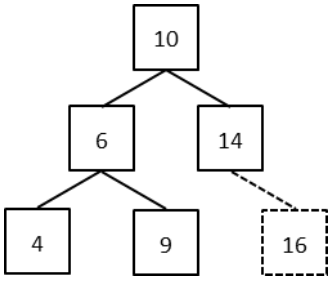

Fig. 3 BST index structure with the newly added node

The linked list structure for the newly added node is as follows.

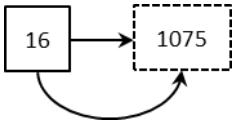

Fig. 4 Linked List structure of the newly added node.

If an element which already exists is to be inserted into the tree, no new node is created in the tree. Instead the associated linked list in extended with the database index of the new node. For e.g., if an element 10 with an index of 1076 is inserted to the BST index, the resultant structure will be as follows.

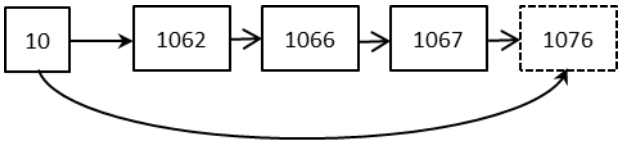

Fig. 5 Linked list of the node after its attribute is inserted at a new database location: 1076

In this case, the structure of the tree remains unchanged.

The pseudo code for insertion operation is as follows:

Insert (root, value, db_index)

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 9, September 2013

```
If (value > root-attribute)
   If (root-right_child is Empty)
            root-right_child-attribute = value
            root-right_child-first-index = db_index
            root-right_child-last-index = db_index
   Else
            Insert (root->right_child, node)
Else If (value < root-attribute)
   If (root-left_child is Empty)
            root-left_child-attribute = value
            root-left_child-first-index = db_index
            root-left_child-last-index = db_index
   Else
            Insert (root->left_child, node)
Else
   root-last-next-index = value
   root-last = root-last-next
```

2) Deletion

The deletion of an entry from the database is achieved by removing the corresponding database index from the BST node of the entry. Deletion can take place under the following scenarios:

2.1) When the index from which the value has to be deleted is not the only index, to which the node points:
Currently the BST index would look like the following.

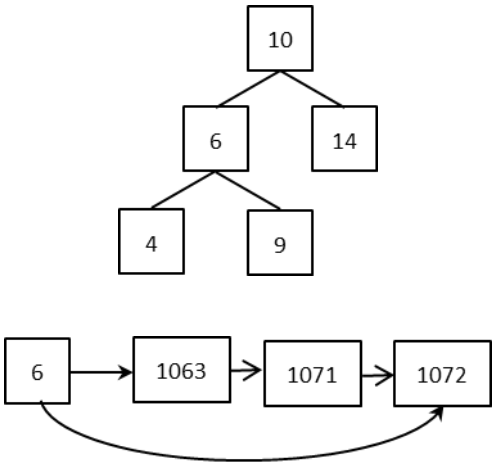

Fig. 6 BST index structure with the linked list of one of its nodes before deletion

For e.g., if the index: 1071 of node '6' has to be deleted, the node '6' is first located in BST using BST look up algorithm. Once it is found, its linked list of indices is searched for the index: 1071. Deleting this index from the linked list implies that the value '6' no more exists in the location given by the index. After deletion, the BST will remain unchanged. The linked list of node '6' would be as follows:

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Vol. 2, Issue 9, September 2013

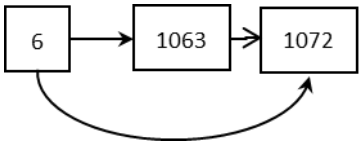

Fig. 7 Linked List structure for the node after its attribute is deleted from the database location: 1071

2.2) When the index to be deleted is the only one, which the node points to:
In this case, the node also has to be deleted, along with the index. As in the above case, the node is located using BST lookup algorithm. Once found, the only entry in its linked list is deleted, before deleting the node and rearranging the BST.
For e.g. if the attribute '6'is removed from database indices 1063 and 1072, the attribute '6' no longer exists in the database. So, its corresponding node should be removed from the BST index structure. Upon deletion of the node, BST would be:

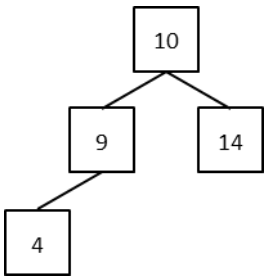

Fig. 8 BST Index structure after the node with attribute '6' is deleted as it is no more stored in the database.

The pseudo code for the deletion operation is as follows:

```
FindMin (node) // finds the inorder successor of the given node
While (node is not NULL)
min_node = node
node = node-left_child.
Endwhile
Return min_node.

Search (node, value) // finds a node in the Binary Search Tree
If (node is NULL)
Return NULL.
Else If (value = node-attribute)
Return node
Else If (value > node-attribute)
    Return Search (node-right_child, value)
Else
Return Search (node-left_child, value)
EndIf.

DeleteBST (value, node) // deletes a node in the binary search tree if its linked list no longer holds any entries

If (value < node-attribute)
    node-left_child = DeleteBST (value, node-left_child)
Else If (value > node-attribute)
    node-right_child = DeleteBST (value, node-right_child)
```

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(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 9, September 2013

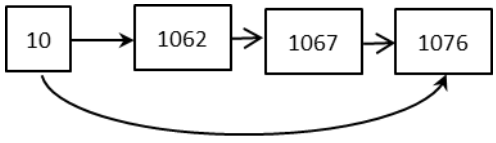
```
Else
If (node has both left_child and right_child)
        successor = findmin(node-right_child)
         node-attribute  = successor-attribute
node-right_child = DeleteBST(node-attribute,node-right_child)
node-first= successor-head
        node-last = successor-last
   Else
         If (node-left_child is NULL)
        node = node-right_child
       Else
                node = node-left_child
       End If
   End If
End If
Return node.

Delete (root, value, db_index) // Main delete method thatinitiates the deletion operation
node = search (root, value)
If (node is not NULL)
        linked_list_ptr=  node-first
        While (linked_list_ptr is not NULL)
                If (linked_list_ptr-value = db_index)
                        temp = linked_list_ptr-next
                linked_list_ptr-value = temp-value
                linked_list_ptr-next = temp-next
                Exit While
                End If
                linked_list_ptr = linked_list_ptr-next
        End While
End If
If (linked_list_ptr is NULL)
        DeleteBST(node_attribute, node)
End If
```

3)Updating

When a database entry is updated to a new value, corresponding changes have to be made in the BST index. There are two types of changes that could result due to a database update.

3.1) When the new value of the field already exists in the BST index as part of another node.

In this case, a node is deleted from the linked list associated with the old value and a node is inserted to the linked list associated with the new value. For e.g., if the attribute value 10 at database index 1066 is updated to 6, the resultant linked list structures are as follows.



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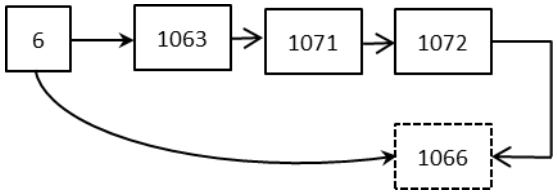
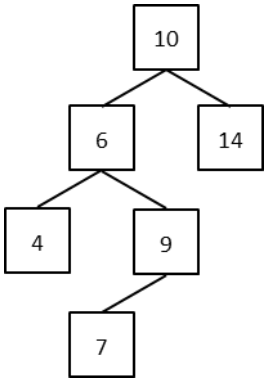


Fig. 9 The linked list structures of the two nodes after updation

3.2) When the new value of the field does not exist in the tree structure.
A new BST index node is created with the updated value and linked list of the old value is adjusted appropriately. This is illustrated with the following tree structure obtained as a result of changing the attribute value 4 at index 1068 to 7. The new BST index structure is as follows.



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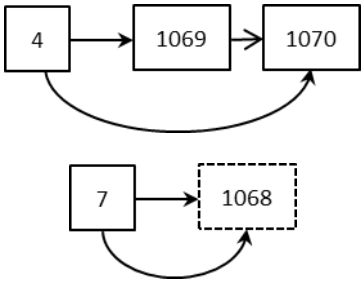

Fig. 10 The BST index with the newly inserted node, along with the linked list of the two nodes involved in the updation operation

IV. CONCLUSION

Column-store has an immense potential for compression due to the similarity of adjacent records. In this paper, we have proposed that a significant level of compression can be achieved without losing out on the performance of the basic operations - insertion, updation and deletion, using a combination of run-length encoding technique and BST indexing representation. Run-length encoding gives a good level of compression, whereas BST indexing performs **O (**log n) insertion, deletion and look-up operations, for a sequence of n runs. Hence we see this as an important work towards understanding the real potential of column-oriented database.

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(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 9, September 2013

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