Data Engineering

Harsh Tomar B21AI049

Implementing a Generic B+ Tree

Attachments

- `BPlusTree` Implementation Code File
  - The code files are divided into different header and c files to provide better implementation and readability of Code.
- Test Suite with Meaningful Test Cases
- We can interact with our code and make a B+ Tree by running the `main_bpt.c` file.
- Result of Test Suite can be found by running the `test_suite.c` file.

What are B+ Trees?

B-Tree

A B-Tree is a self-balancing tree data structure that maintains sorted data and allows searches, sequential access, insertions, and deletions in **logarithmic time.** The B-Tree generalizes the Binary Search Tree, allowing for **nodes** with more than two children. Unlike other Self-Balancing Binary Search Trees, the B-Tree is well suited for storage systems that read and write relatively large blocks of data, such as Databases and File Systems.

B+-Tree

A **B+ tree** is an m-ary tree with a variable but often large number of children per node. A B+ tree consists of a root, internal nodes and leaves.1(https://en.wikipedia.org/wiki/B%2B_tree#cite_note-Navathe-1) The root may be either a leaf or a node with two or more children.

A B+ tree can be viewed as a B-tree in which each node contains only keys (not key–value pairs), and to which an additional level is added at the bottom with linked leaves.

(The definition is taken from WikiPedia)

Implementing Generic B+ Tree

Design Decisions

- Insert < key > < value > pairs in the Tree
- Duplicate Keys are handled by Maintaining a linked-list of duplicate values. For example, if we add the key `9` two times, we get `9 -> 9`

Challenges

- Handling Insertion and Deletion Algorithms
- Inserting Duplicate Keys
- Deleting Duplicate Keys
- Printing the Tree
- Searching for Duplicate Keys

Code

Class / Structure of a Node

Non Leaf Nodes

Minimum and Maximum number of entries n is bounded by the order d of the B+-Tree:

$$d <= n <= 2 * d$$

for root node

$$rootnode : (1 <= n <= 2 * d)$$

- A node contains n+1 pointers.
- Pointers pi points to a subtree in which all the key values k are such that ki <= k < ki+1
- Ex (p0 points to a subtree with key values < k1, pn points to a subtree with key values >= kn)

Leaf Nodes

B+-Tree Leaf nodes contain pointers to data records. A leaf node entry with key value k is denoted as k* as before.

Handling Duplicate Values

We handle (insert, delete) duplicate values by maintaining a chain of values under the same key :
For example

We insert
1, 2, 3, 4, 5, 6, 7, 8, 9, 10
in our tree,

then we add duplicate key `10` with different values (can be same as well) `11` `12` and `13`

The leaf structure looks like this

```
> t
5 |
3 | 7 9 |
1 2 | 3 4 | 5 6 | 7 8 | 9 10 |
> l
1 (1)2 (2) | 3 (3)4 (4) | 5 (5)6 (6) | 7 (7)8 (8) | 9 (9)10 (10->11->12->13)
>
```

now we add duplicate key `9` with same values `9` again

```
> i 9
5 |
3 | 7 9 |
1 2 | 3 4 | 5 6 | 7 8 | 9 10 |
> l
1 (1)2 (2) | 3 (3)4 (4) | 5 (5)6 (6) | 7 (7)8 (8) | 9 (9->9)10 (10->11->12->13)
>
```

Deleting Duplicate Keys

Let's delete the value `12` from the Key 10

```
> d 10
Do you want to delete the whole key? type y for yes: n
(10->11->12->13) Which value of the key do you want to delete?
12

5 |
3 | 7 9 |
1 2 | 3 4 | 5 6 | 7 8 | 9 10 |
> l
1 (1)2 (2) | 3 (3)4 (4) | 5 (5)6 (6) | 7 (7)8 (8) | 9 (9->9)10 (10->11->13)
>
```

Let's delete the whole key `9` from the B+ Tree

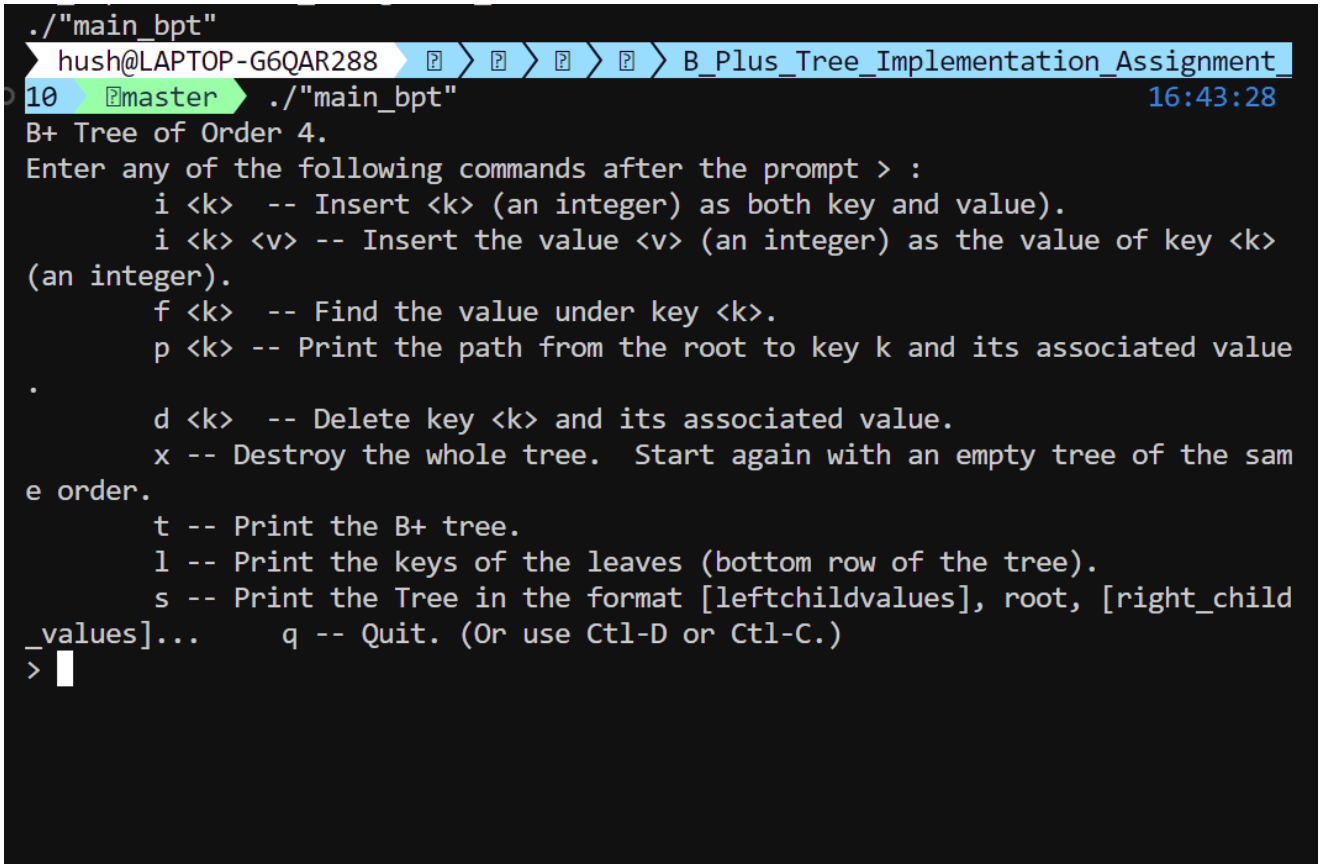
```
> d 9
Do you want to delete the whole key? type y for yes: y
5 |
3 | 7 |
1 2 | 3 4 | 5 6 | 7 8 10 |
> l
1 (1)2 (2) | 3 (3)4 (4) | 5 (5)6 (6) | 7 (7)8 (8)10 (10->11->13)
>
```

Question 1

Insert the keys based on the sequences provided below in the B+ - Tree and show the tree after each insertion.

Insertion sequence for my roll number (odd) (B21AI049 => 49):
2, 8, 24, 12, 49, 54, 42, 20, 8, 4

Terminal Output



Now, we insert the required sequence of keys

```
> i 2
2 |
> i 8
2 8 |
> i 24
2 8 24 |
> i 12
12 |
2 8 | 12 24 |
> i 49
12 |
2 8 | 12 24 49 |
> i 54
12 49 |
2 8 | 12 24 | 49 54 |
> i 42
12 49 |
2 8 | 12 24 42 | 49 54 |
> i 20
12 24 49 |
2 8 | 12 20 | 24 42 | 49 54 |
> i 8
12 24 49 |
2 8 | 12 20 | 24 42 | 49 54 |
> i 4
12 24 49 |
2 4 8 | 12 20 | 24 42 | 49 54 |
>
```

Final Tree Structure

```
12 24 49 |
2 4 8 | 12 20 | 24 42 | 49 54 |
```

Final Leaf `Level` Structure

```
> l
2 (2)4 (4)8 (8->8) | 12 (12)20 (20) | 24 (24)42 (42) | 49 (49)54 (54)
```

Output of `toString()`:

```
2 4 8 | 12 20 | 24 42 | 49 54 |
> s
[2, 4, 8] 12 , [12, 20] 24 , [24, 42] 49 , [49, 54]
```

We can confirm that the tree-structure is printed in `[left_child_values], root, [right_child_values], ...` fashion.

Question 2

Create a `toString()` function to return B+-Tree in string format such as "[left child values], root, [right child values], [left child values], root, [right child values].....".

The code for the `toString()` function can be found in `to_string.c` file.

Output of `to_string` function is also used in verifying the `test_cases`. Further, we can also use output of Search functions to verify different test cases.

Question 3

Print the results of search and deletion of the last two digits of your roll number (B21AI049 => 49) in the above tree and report the final B+ - Tree.

```
> t
12 24 49 |
2 4 8 | 12 20 | 24 42 | 49 54 |
> f 49
Record at 0x55d757e41cc0 -- key 49, value 49.
> p 49
[12 24 49] 3 ->
Leaf [49 54] ->
Record at 0x55d757e41cc0 -- key 49, value 49.
>
```

Searching for 49

In the above tree, when we search for the key 49 by using the command `f 49` we get that the key and it's value is found in the tree.

`p 49` prints the path from the root to the key 49, as we can confirm that from the root node we pick the 3rd (0 indexing) child to get the Leaf `[49, 54]`.

Deleting 49

```
> t
12 24 49 |
2 4 8 | 12 20 | 24 42 | 49 54 |
> f 49
Record at 0x55d757e41cc0 -- key 49, value 49.
> p 49
[12 24 49] 3 ->
Leaf [49 54] ->
Record at 0x55d757e41cc0 -- key 49, value 49.
> d 49
Do you want to delete the whole key? type y for yes: y
12 24 |
2 4 8 | 12 20 | 24 42 54 |
> t
12 24 |
2 4 8 | 12 20 | 24 42 54 |
> f 49
Record not found under key 49.
> t
12 24 |
2 4 8 | 12 20 | 24 42 54 |
```

As we can observe, the key 49 has been removed from the tree, and now we can't search for it as well.

Tree Before Deleting

```
> t
12 24 49 |
2 4 8 | 12 20 | 24 42 | 49 54 |
```

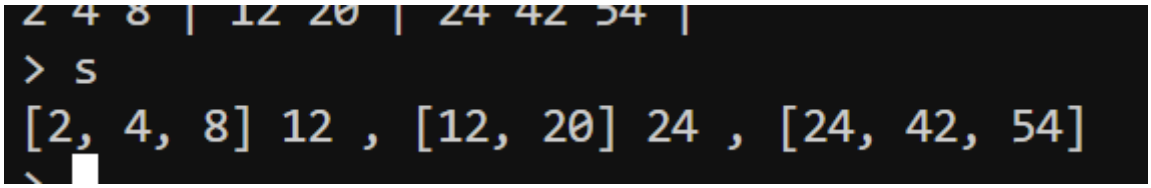
ToString Before Deleting

```
> s
[2, 4, 8] 12 , [12, 20] 24 , [24, 42] 49 , [49, 54]
```

Tree after Deleting

```
> t
12 24 |
2 4 8 | 12 20 | 24 42 54 |
```

ToString after Deleting



ThankYou :D