B-Tree | Set 3 (Delete)

It is recommended to refer following posts as prerequisite of this post.

B-Tree | Set 1 (Introduction)
B-Tree | Set 2 (Insert)

B-Tree is a type of a multi-way search tree. So, if you are not familiar with multi-way search trees in general, it is better to take a look at this video lecture from IIT-Delhi, before proceeding further. Once you get the basics of a multi-way search tree clear, B-Tree operations will be easier to understand.

Source of the following explanation and algorithm is Introduction to Algorithms 3rd Edition by Clifford Stein, Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest

Deletion process:
Deletion from a B-tree is more complicated than insertion, because we can delete a key from any node-not just a leaf—and when we delete a key from an internal node, we will have to rearrange the node's children.

As in insertion, we must make sure the deletion doesn't violates the B-tree properties. Just as we had to ensure that a node didn't get too big due to insertion, we must ensure that a node doesn't get too small during deletion (except that the root is allowed to have fewer than the minimum number t-1 of keys). Just as a simple insertion algorithm might have to back up if a node on the path to where the key was to be inserted was full, a simple approach to deletion might have to back up if a node (other than the root) along the path to where the key is to be deleted has the minimum number of keys.

The deletion procedure deletes the key k from the subtree rooted at x. This procedure

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guarantees that whenever it calls itself recursively on a node x, the number of keys in x is at least the minimum degree t . Note that this condition requires one more key than the minimum required by the usual B-tree conditions, so that sometimes a key may have to be moved into a child node before recursion descends to that child. This strengthened condition allows us to delete a key from the tree in one downward pass without having to “back up” (with one exception, which we’ll explain). You should interpret the following specification for deletion from a B-tree with the understanding that if the root node x ever becomes an internal node having no keys (this situation can occur in cases 2c and 3b then we delete x, and x’s only child x.c1 becomes the new root of the tree, decreasing the height of the tree by one and preserving the property that the root of the tree contains at least one key (unless the tree is empty).

We sketch how deletion works with various cases of deleting keys from a B-tree.

1. If the key k is in node x and x is a leaf, delete the key k from x.

2. If the key k is in node x and x is an internal node, do the following.

a) If the child y that precedes k in node x has at least t keys, then find the predecessor k0 of k in the sub-tree rooted at y. Recursively delete k0, and replace k by k0 in x. (We can find k0 and delete it in a single downward pass.)

b) If y has fewer than t keys, then, symmetrically, examine the child z that follows k in node x. If z has at least t keys, then find the successor k0 of k in the subtree rooted at z. Recursively delete k0, and replace k by k0 in x. (We can find k0 and delete it in a single downward pass.)

c) Otherwise, if both y and z have only t-1 keys, merge k and all of z into y, so that x loses both k and the pointer to z, and y now contains 2t-1 keys. Then free z and recursively delete k from y.

3. If the key k is not present in internal node x, determine the root x.c(i) of the appropriate subtree that must contain k, if k is in the tree at all. If x.c(i) has only t-1 keys, execute step 3a or 3b as necessary to guarantee that we descend to a node containing at least t keys. Then finish by recursing on the appropriate child of x.

a) If x.c(i) has only t-1 keys but has an immediate sibling with at least t keys, give x.c(i) an extra key by moving a key from x down into x.c(i), moving a key from x.c(i) ’s immediate left or right sibling up into x, and moving the appropriate child pointer from the sibling into x.c(i).

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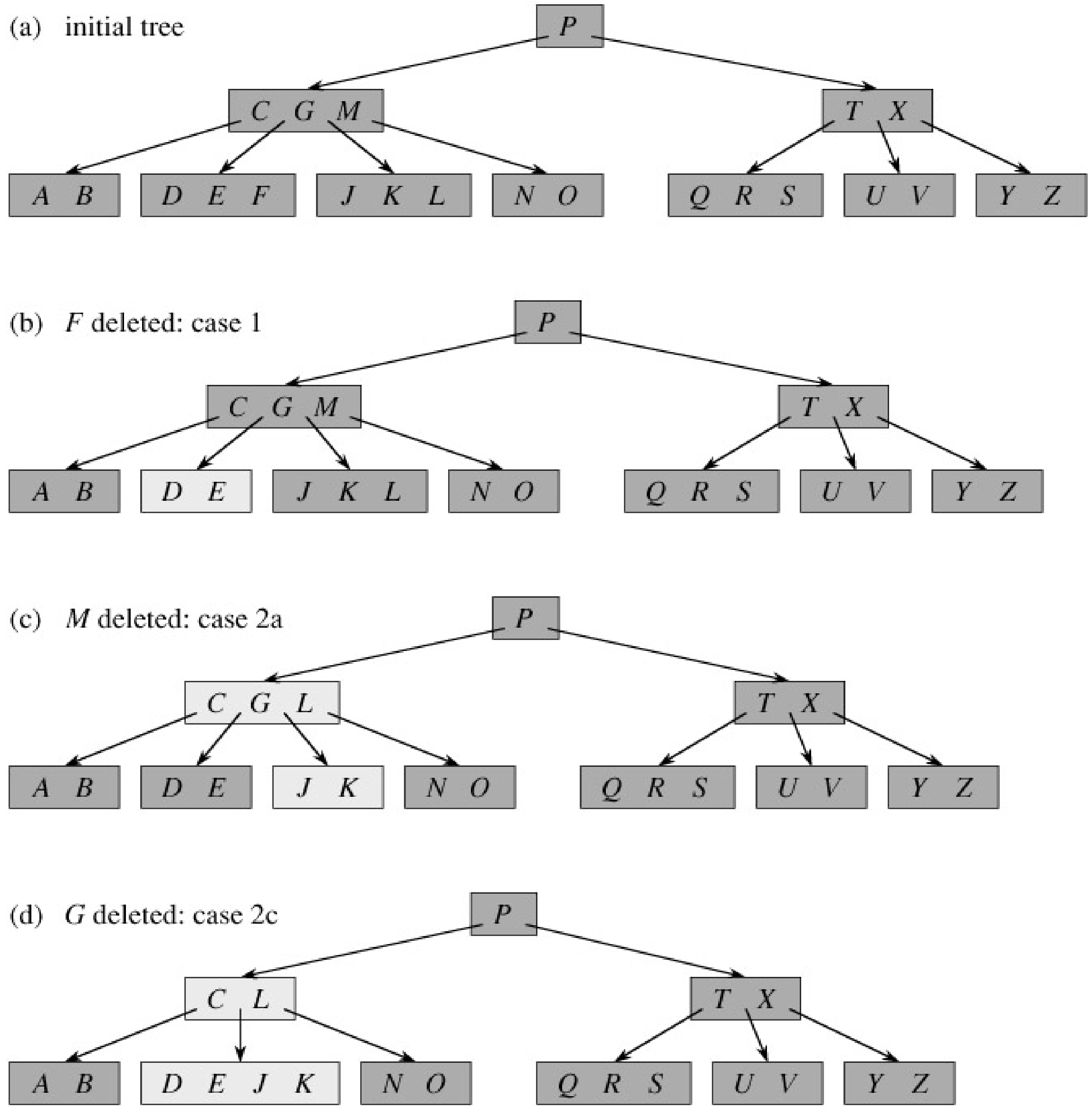
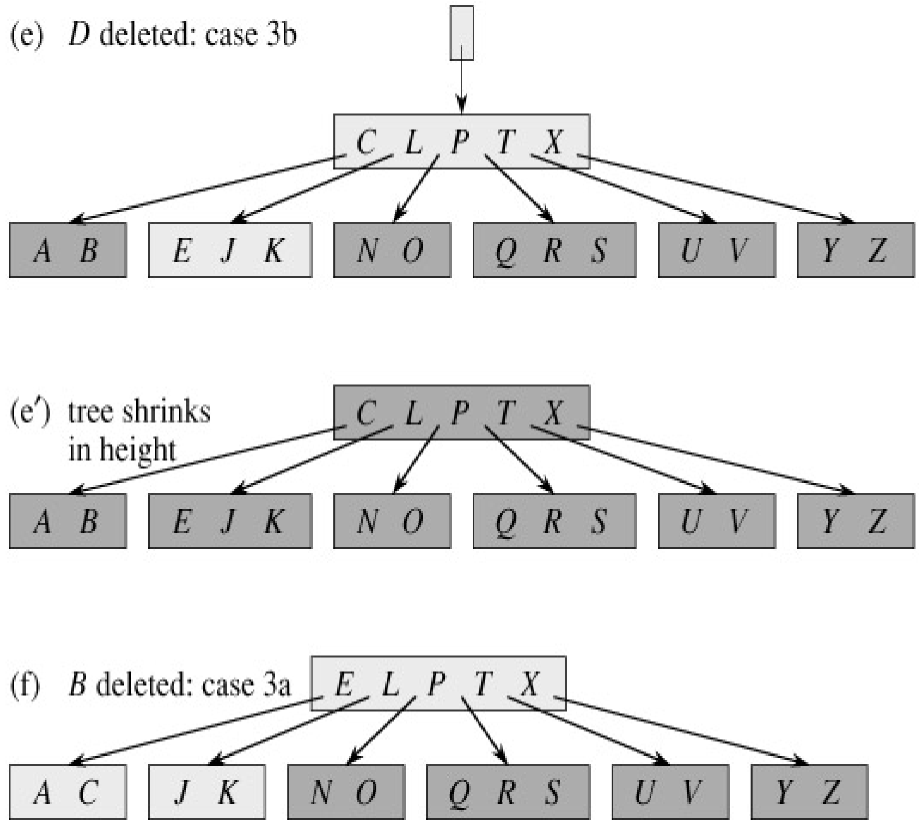
b) If x.c(i) and both of x.c(i)'s immediate siblings have t-1 keys, merge x.c(i) with one sibling, which involves moving a key from x down into the new merged node to become the median key for that node.

Since most of the keys in a B-tree are in the leaves, deletion operations are most often used to delete keys from leaves. The recursive delete procedure then acts in one downward pass through the tree, without having to back up. When deleting a key in an internal node, however, the procedure makes a downward pass through the tree but may have to return to the node from which the key was deleted to replace the key with its predecessor or successor (cases 2a and 2b).

The following figures from CLRS book explain the deletion porcess.



(a) initial tree
P
C G M
T X
A B
D E F
J K L
N O
Q R S
U V
Y Z
(b) F deleted: case 1
P
C G M
T X
A B
D E
J K L
N O
Q R S
U V
Y Z
(c) M deleted: case 2a
P
C G L
T X
A B
D E
J K
N O
Q R S
U V
Y Z
(d) G deleted: case 2c
P
C L
T X
A B
D E J K
N O
Q R S
U V
Y Z



Implementation:
Following is C++ implementation of deletion process.

```
/* The following program performs deletion on a B-Tree. It contains fu
   specific for deletion along with all the other functions provided i
   previous articles on B-Trees. See http://www.geeksforgeeks.org/b-tr
   for previous article.

   The deletion function has been compartmentalized into 8 functions f
   of understanding and clarity

   The following functions are exclusive for deletion
   In class BTreeNode:
    1) remove
    2) removeFromLeaf
    3) removeFromNonLeaf
    4) getPred
    5) getSucc
    6) borrowFromPrev
```

```
    7) borrowFromNext
    8) merge
    9) findKey

   In class BTree:
     1) remove

  The removal of a key from a B-Tree is a fairly complicated process.
  all the 6 different cases that might arise while removing a key.

  Testing: The code has been tested using the B-Tree provided in the C
  in the main function ) along with other cases.

  Reference: CLRS3 - Chapter 18 - (499-502)
  It is advised to read the material in CLRS before taking a look at t

#include<iostream>
using namespace std;

// A BTree node
class BTreeNode
{
    int *keys;  // An array of keys
    int t;      // Minimum degree (defines the range for number of key
    BTreeNode **C; // An array of child pointers
    int n;     // Current number of keys
    bool leaf; // Is true when node is leaf. Otherwise false

public:

    BTreeNode(int _t, bool _leaf);   // Constructor

    // A function to traverse all nodes in a subtree rooted with this
    void traverse();

    // A function to search a key in subtree rooted with this node.
    BTreeNode *search(int k);   // returns NULL if k is not present.

    // A function that returns the index of the first key that is grea
    // or equal to k
    int findKey(int k);

    // A utility function to insert a new key in the subtree rooted wi
    // this node. The assumption is, the node must be non-full when th
    // function is called
    void insertNonFull(int k);
```

```
    // A utility function to split the child y of this node. i is inde
    // of y in child array C[].  The Child y must be full when this
    // function is called
    void splitChild(int i, BTreeNode *y);

    // A wrapper function to remove the key k in subtree rooted with
    // this node.
    void remove(int k);

    // A function to remove the key present in idx-th position in
    // this node which is a leaf
    void removeFromLeaf(int idx);

    // A function to remove the key present in idx-th position in
    // this node which is a non-leaf node
    void removeFromNonLeaf(int idx);

    // A function to get the predecessor of the key- where the key
    // is present in the idx-th position in the node
    int getPred(int idx);

    // A function to get the successor of the key- where the key
    // is present in the idx-th position in the node
    int getSucc(int idx);

    // A function to fill up the child node present in the idx-th
    // position in the C[] array if that child has less than t-1 keys
    void fill(int idx);

    // A function to borrow a key from the C[idx-1]-th node and place
    // it in C[idx]th node
    void borrowFromPrev(int idx);

    // A function to borrow a key from the C[idx+1]-th node and place
    // in C[idx]th node
    void borrowFromNext(int idx);

    // A function to merge idx-th child of the node with (idx+1)th chi
    // the node
    void merge(int idx);

    // Make BTree friend of this so that we can access private members
    // this class in BTree functions
    friend class BTree;
};

class BTree
```

```
{
    BTreeNode *root; // Pointer to root node
    int t;  // Minimum degree
public:

    // Constructor (Initializes tree as empty)
    BTree(int _t)
    {
        root = NULL;
        t = _t;
    }

    void traverse()
    {
        if (root != NULL) root->traverse();
    }

    // function to search a key in this tree
    BTreeNode* search(int k)
    {
        return (root == NULL)? NULL : root->search(k);
    }

    // The main function that inserts a new key in this B-Tree
    void insert(int k);

    // The main function that removes a new key in thie B-Tree
    void remove(int k);

};

BTreeNode::BTreeNode(int t1, bool leaf1)
{
    // Copy the given minimum degree and leaf property
    t = t1;
    leaf = leaf1;

    // Allocate memory for maximum number of possible keys
    // and child pointers
    keys = new int[2*t-1];
    C = new BTreeNode *[2*t];

    // Initialize the number of keys as 0
    n = 0;
}

// A utility function that returns the index of the first key that is
```

```
// greater than or equal to k
int BTreeNode::findKey(int k)
{
    int idx=0;
    while (idx<n && keys[idx] < k)
        ++idx;
    return idx;
}

// A function to remove the key k from the sub-tree rooted with this n
void BTreeNode::remove(int k)
{
    int idx = findKey(k);

    // The key to be removed is present in this node
    if (idx < n && keys[idx] == k)
    {

        // If the node is a leaf node - removeFromLeaf is called
        // Otherwise, removeFromNonLeaf function is called
        if (leaf)
            removeFromLeaf(idx);
        else
            removeFromNonLeaf(idx);
    }
    else
    {

        // If this node is a leaf node, then the key is not present in
        if (leaf)
        {
            cout << "The key "<< k <<" is does not exist in the tree\n
            return;
        }

        // The key to be removed is present in the sub-tree rooted wit
        // The flag indicates whether the key is present in the sub-tr
        // with the last child of this node
        bool flag = ( (idx==n)? true : false );

        // If the child where the key is supposed to exist has less th
        // we fill that child
        if (C[idx]->n < t)
            fill(idx);

        // If the last child has been merged, it must have merged with
        // child and so we recurse on the (idx-1)th child. Else, we re
```

```
            // (idx)th child which now has atleast t keys
            if (flag && idx > n)
                C[idx-1]->remove(k);
            else
                C[idx]->remove(k);
        }
        return;
    }

    // A function to remove the idx-th key from this node - which is a lea
    void BTreeNode::removeFromLeaf (int idx)
    {

        // Move all the keys after the idx-th pos one place backward
        for (int i=idx+1; i<n; ++i)
            keys[i-1] = keys[i];

        // Reduce the count of keys
        n--;

        return;
    }

    // A function to remove the idx-th key from this node - which is a non
    void BTreeNode::removeFromNonLeaf(int idx)
    {

        int k = keys[idx];

        // If the child that precedes k (C[idx]) has atleast t keys,
        // find the predecessor 'pred' of k in the subtree rooted at
        // C[idx]. Replace k by pred. Recursively delete pred
        // in C[idx]
        if (C[idx]->n >= t)
        {
            int pred = getPred(idx);
            keys[idx] = pred;
            C[idx]->remove(pred);
        }

        // If the child C[idx] has less that t keys, examine C[idx+1].
        // If C[idx+1] has atleast t keys, find the successor 'succ' of k
        // the subtree rooted at C[idx+1]
        // Replace k by succ
        // Recursively delete succ in C[idx+1]
        else if  (C[idx+1]->n >= t)
        {
```

```
            int succ = getSucc(idx);
            keys[idx] = succ;
            C[idx+1]->remove(succ);
        }

        // If both C[idx] and C[idx+1] has less that t keys,merge k and al
        // into C[idx]
        // Now C[idx] contains 2t-1 keys
        // Free C[idx+1] and recursively delete k from C[idx]
        else
        {
            merge(idx);
            C[idx]->remove(k);
        }
        return;
    }

    // A function to get predecessor of keys[idx]
    int BTreeNode::getPred(int idx)
    {
        // Keep moving to the right most node until we reach a leaf
        BTreeNode *cur=C[idx];
        while (!cur->leaf)
            cur = cur->C[cur->n];

        // Return the last key of the leaf
        return cur->keys[cur->n-1];
    }

    int BTreeNode::getSucc(int idx)
    {

        // Keep moving the left most node starting from C[idx+1] until we
        BTreeNode *cur = C[idx+1];
        while (!cur->leaf)
            cur = cur->C[0];

        // Return the first key of the leaf
        return cur->keys[0];
    }

    // A function to fill child C[idx] which has less than t-1 keys
    void BTreeNode::fill(int idx)
    {

        // If the previous child(C[idx-1]) has more than t-1 keys, borrow
        // from that child
```

```
    if (idx!=0 && C[idx-1]->n>=t)
        borrowFromPrev(idx);

    // If the next child(C[idx+1]) has more than t-1 keys, borrow a ke
    // from that child
    else if (idx!=n && C[idx+1]->n>=t)
        borrowFromNext(idx);

    // Merge C[idx] with its sibling
    // If C[idx] is the last child, merge it with with its previous si
    // Otherwise merge it with its next sibling
    else
    {
        if (idx != n)
            merge(idx);
        else
            merge(idx-1);
    }
    return;
}

// A function to borrow a key from C[idx-1] and insert it
// into C[idx]
void BTreeNode::borrowFromPrev(int idx)
{

    BTreeNode *child=C[idx];
    BTreeNode *sibling=C[idx-1];

    // The last key from C[idx-1] goes up to the parent and key[idx-1]
    // from parent is inserted as the first key in C[idx]. Thus, the
    // sibling one key and child gains one key

    // Moving all key in C[idx] one step ahead
    for (int i=child->n-1; i>=0; --i)
        child->keys[i+1] = child->keys[i];

    // If C[idx] is not a leaf, move all its child pointers one step a
    if (!child->leaf)
    {
        for(int i=child->n; i>=0; --i)
            child->C[i+1] = child->C[i];
    }

    // Setting child's first key equal to keys[idx-1] from the current
    child->keys[0] = keys[idx-1];
```

```
        // Moving sibling's last child as C[idx]'s first child
        if (!leaf)
            child->C[0] = sibling->C[sibling->n];

        // Moving the key from the sibling to the parent
        // This reduces the number of keys in the sibling
        keys[idx-1] = sibling->keys[sibling->n-1];

        child->n += 1;
        sibling->n -= 1;

        return;
    }

    // A function to borrow a key from the C[idx+1] and place
    // it in C[idx]
    void BTreeNode::borrowFromNext(int idx)
    {

        BTreeNode *child=C[idx];
        BTreeNode *sibling=C[idx+1];

        // keys[idx] is inserted as the last key in C[idx]
        child->keys[(child->n)] = keys[idx];

        // Sibling's first child is inserted as the last child
        // into C[idx]
        if (!(child->leaf))
            child->C[(child->n)+1] = sibling->C[0];

        //The first key from sibling is inserted into keys[idx]
        keys[idx] = sibling->keys[0];

        // Moving all keys in sibling one step behind
        for (int i=1; i<sibling->n; ++i)
            sibling->keys[i-1] = sibling->keys[i];

        // Moving the child pointers one step behind
        if (!sibling->leaf)
        {
            for(int i=1; i<=sibling->n; ++i)
                sibling->C[i-1] = sibling->C[i];
        }

        // Increasing and decreasing the key count of C[idx] and C[idx+1]
        // respectively
        child->n += 1;
```

```
    sibling->n -= 1;

    return;
}

// A function to merge C[idx] with C[idx+1]
// C[idx+1] is freed after merging
void BTreeNode::merge(int idx)
{
    BTreeNode *child = C[idx];
    BTreeNode *sibling = C[idx+1];

    // Pulling a key from the current node and inserting it into (t-1)
    // position of C[idx]
    child->keys[t-1] = keys[idx];

    // Copying the keys from C[idx+1] to C[idx] at the end
    for (int i=0; i<sibling->n; ++i)
        child->keys[i+t] = sibling->keys[i];

    // Copying the child pointers from C[idx+1] to C[idx]
    if (!child->leaf)
    {
        for(int i=0; i<=sibling->n; ++i)
            child->C[i+t] = sibling->C[i];
    }

    // Moving all keys after idx in the current node one step before -
    // to fill the gap created by moving keys[idx] to C[idx]
    for (int i=idx+1; i<n; ++i)
        keys[i-1] = keys[i];

    // Moving the child pointers after (idx+1) in the current node one
    // step before
    for (int i=idx+2; i<=n; ++i)
        C[i-1] = C[i];

    // Updating the key count of child and the current node
    child->n += sibling->n+1;
    n--;

    // Freeing the memory occupied by sibling
    delete(sibling);
    return;
}

// The main function that inserts a new key in this B-Tree
```

```
void BTree::insert(int k)
{
    // If tree is empty
    if (root == NULL)
    {
        // Allocate memory for root
        root = new BTreeNode(t, true);
        root->keys[0] = k;  // Insert key
        root->n = 1;  // Update number of keys in root
    }
    else // If tree is not empty
    {
        // If root is full, then tree grows in height
        if (root->n == 2*t-1)
        {
            // Allocate memory for new root
            BTreeNode *s = new BTreeNode(t, false);

            // Make old root as child of new root
            s->C[0] = root;

            // Split the old root and move 1 key to the new root
            s->splitChild(0, root);

            // New root has two children now.  Decide which of the
            // two children is going to have new key
            int i = 0;
            if (s->keys[0] < k)
                i++;
            s->C[i]->insertNonFull(k);

            // Change root
            root = s;
        }
        else  // If root is not full, call insertNonFull for root
            root->insertNonFull(k);
    }
}

// A utility function to insert a new key in this node
// The assumption is, the node must be non-full when this
// function is called
void BTreeNode::insertNonFull(int k)
{
    // Initialize index as index of rightmost element
    int i = n-1;
```

```
    // If this is a leaf node
    if (leaf == true)
    {
        // The following loop does two things
        // a) Finds the location of new key to be inserted
        // b) Moves all greater keys to one place ahead
        while (i >= 0 && keys[i] > k)
        {
            keys[i+1] = keys[i];
            i--;
        }

        // Insert the new key at found location
        keys[i+1] = k;
        n = n+1;
    }
    else // If this node is not leaf
    {
        // Find the child which is going to have the new key
        while (i >= 0 && keys[i] > k)
            i--;

        // See if the found child is full
        if (C[i+1]->n == 2*t-1)
        {
            // If the child is full, then split it
            splitChild(i+1, C[i+1]);

            // After split, the middle key of C[i] goes up and
            // C[i] is splitted into two.  See which of the two
            // is going to have the new key
            if (keys[i+1] < k)
                i++;
        }
        C[i+1]->insertNonFull(k);
    }
}

// A utility function to split the child y of this node
// Note that y must be full when this function is called
void BTreeNode::splitChild(int i, BTreeNode *y)
{
    // Create a new node which is going to store (t-1) keys
    // of y
    BTreeNode *z = new BTreeNode(y->t, y->leaf);
    z->n = t - 1;
```

```
    // Copy the last (t-1) keys of y to z
    for (int j = 0; j < t-1; j++)
        z->keys[j] = y->keys[j+t];

    // Copy the last t children of y to z
    if (y->leaf == false)
    {
        for (int j = 0; j < t; j++)
            z->C[j] = y->C[j+t];
    }

    // Reduce the number of keys in y
    y->n = t - 1;

    // Since this node is going to have a new child,
    // create space of new child
    for (int j = n; j >= i+1; j--)
        C[j+1] = C[j];

    // Link the new child to this node
    C[i+1] = z;

    // A key of y will move to this node. Find location of
    // new key and move all greater keys one space ahead
    for (int j = n-1; j >= i; j--)
        keys[j+1] = keys[j];

    // Copy the middle key of y to this node
    keys[i] = y->keys[t-1];

    // Increment count of keys in this node
    n = n + 1;
}

// Function to traverse all nodes in a subtree rooted with this node
void BTreeNode::traverse()
{
    // There are n keys and n+1 children, travers through n keys
    // and first n children
    int i;
    for (i = 0; i < n; i++)
    {
        // If this is not leaf, then before printing key[i],
        // traverse the subtree rooted with child C[i].
        if (leaf == false)
            C[i]->traverse();
        cout << " " << keys[i];
```

```
    }

    // Print the subtree rooted with last child
    if (leaf == false)
        C[i]->traverse();
}

// Function to search key k in subtree rooted with this node
BTreeNode *BTreeNode::search(int k)
{
    // Find the first key greater than or equal to k
    int i = 0;
    while (i < n && k > keys[i])
        i++;

    // If the found key is equal to k, return this node
    if (keys[i] == k)
        return this;

    // If key is not found here and this is a leaf node
    if (leaf == true)
        return NULL;

    // Go to the appropriate child
    return C[i]->search(k);
}

void BTree::remove(int k)
{
    if (!root)
    {
        cout << "The tree is empty\n";
        return;
    }

    // Call the remove function for root
    root->remove(k);

    // If the root node has 0 keys, make its first child as the new ro
    //  if it has a child, otherwise set root as NULL
    if (root->n==0)
    {
        BTreeNode *tmp = root;
        if (root->leaf)
            root = NULL;
        else
            root = root->C[0];
```

```
            // Free the old root
            delete tmp;
        }
        return;
    }

    // Driver program to test above functions
    int main()
    {
        BTree t(3); // A B-Tree with minium degree 3

        t.insert(1);
        t.insert(3);
        t.insert(7);
        t.insert(10);
        t.insert(11);
        t.insert(13);
        t.insert(14);
        t.insert(15);
        t.insert(18);
        t.insert(16);
        t.insert(19);
        t.insert(24);
        t.insert(25);
        t.insert(26);
        t.insert(21);
        t.insert(4);
        t.insert(5);
        t.insert(20);
        t.insert(22);
        t.insert(2);
        t.insert(17);
        t.insert(12);
        t.insert(6);

        cout << "Traversal of tree constructed is\n";
        t.traverse();
        cout << endl;

        t.remove(6);
        cout << "Traversal of tree after removing 6\n";
        t.traverse();
        cout << endl;

        t.remove(13);
        cout << "Traversal of tree after removing 13\n";
```

```
    t.traverse();
    cout << endl;

    t.remove(7);
    cout << "Traversal of tree after removing 7\n";
    t.traverse();
    cout << endl;

    t.remove(4);
    cout << "Traversal of tree after removing 4\n";
    t.traverse();
    cout << endl;

    t.remove(2);
    cout << "Traversal of tree after removing 2\n";
    t.traverse();
    cout << endl;

    t.remove(16);
    cout << "Traversal of tree after removing 16\n";
    t.traverse();
    cout << endl;

    return 0;
}
```

Output:

```
Traversal of tree constructed is
 1 2 3 4 5 6 7 10 11 12 13 14 15 16 17 18 19 20 21 22 24 25 26
Traversal of tree after removing 6
 1 2 3 4 5 7 10 11 12 13 14 15 16 17 18 19 20 21 22 24 25 26
Traversal of tree after removing 13
 1 2 3 4 5 7 10 11 12 14 15 16 17 18 19 20 21 22 24 25 26
Traversal of tree after removing 7
 1 2 3 4 5 10 11 12 14 15 16 17 18 19 20 21 22 24 25 26
Traversal of tree after removing 4
 1 2 3 5 10 11 12 14 15 16 17 18 19 20 21 22 24 25 26
Traversal of tree after removing 2
 1 3 5 10 11 12 14 15 16 17 18 19 20 21 22 24 25 26
Traversal of tree after removing 16
 1 3 5 10 11 12 14 15 17 18 19 20 21 22 24 25 26
```

This article is contributed by **Balasubramanian.N** . Please write comments if you find anything incorrect, or you want to share more information about the topic discussed above.

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rahul23 • 7 months ago

@GEEKFORGEEKS

@ Balasubramanian.N

Please explain this with example

You should interpret the following specification for deletion from a B-tree with t
ever becomes an internal node having no keys (this situation can occur in cas
only child x.c1 becomes the new root of the tree, decreasing the height of the
that the root of the tree contains at least one key (unless the tree is empty).

Do we need to maintain (t-1)+1 as minimum keys for each node instead of (t-

Please let me know if m missing anything,

Thanks in advance

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rahul23 ➦ rahul23 • 7 months ago

As per this we must have 3 keys for each node,instead of this some n
a node gets a key from above to form t-1 keys constraint and we move
has only 3 children then it will now have 2 children....so it will have t-1 k
also?

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