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Data Structures and Algorithms

Assignment 1

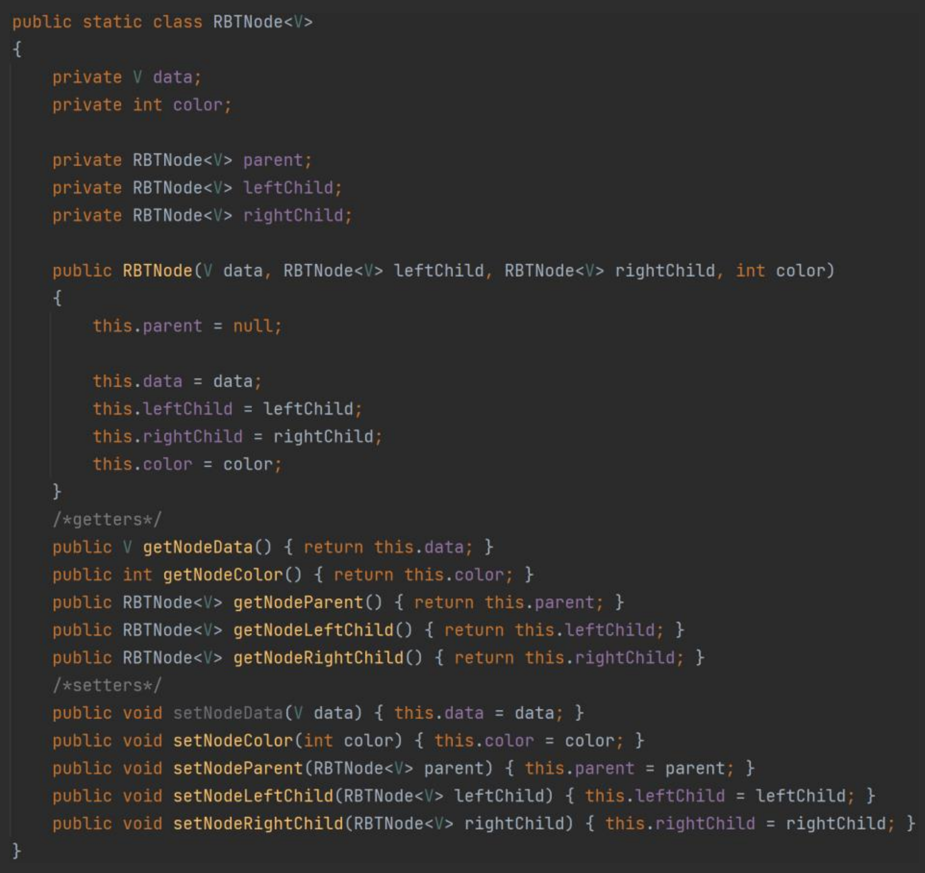
Red-Black Tree:

Memory usage: **O(n)**

Time complexity:

Function	Best case	Worst case
Insert	**O**(**log**(**n**))	**O**(**log**(**n**))
Search	**O**(**log**(**n**))	**O**(**log**(**n**))
Delete	**O**(**log**(**n**))	**O**(**log**(**n**))

Node structure:



```java
public static class RBTNode<V>
{
    private V data;
    private int color;

    private RBTNode<V> parent;
    private RBTNode<V> leftChild;
    private RBTNode<V> rightChild;

    public RBTNode(V data, RBTNode<V> leftChild, RBTNode<V> rightChild, int color)
    {
        this.parent = null;

        this.data = data;
        this.leftChild = leftChild;
        this.rightChild = rightChild;
        this.color = color;
    }
    /*getters*/
    public V getNodeData() { return this.data; }
    public int getNodeColor() { return this.color; }
    public RBTNode<V> getNodeParent() { return this.parent; }
    public RBTNode<V> getNodeLeftChild() { return this.leftChild; }
    public RBTNode<V> getNodeRightChild() { return this.rightChild; }
    /*setters*/
    public void setNodeData(V data) { this.data = data; }
    public void setNodeColor(int color) { this.color = color; }
    public void setNodeParent(RBTNode<V> parent) { this.parent = parent; }
    public void setNodeLeftChild(RBTNode<V> leftChild) { this.leftChild = leftChild; }
    public void setNodeRightChild(RBTNode<V> rightChild) { this.rightChild = rightChild; }
}
```

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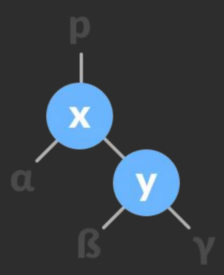
For balancing tree, we use such methods, like:

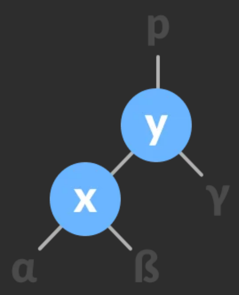
1. Left Rotate:

In left rotation, the arrangement of the nodes on the right is transformed into the arrangements on the left node.

Initial tree:



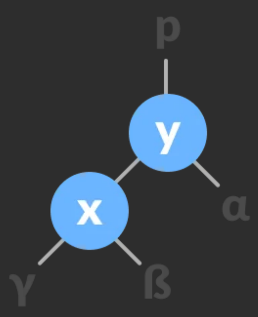
Left Rotate:



2. Right Rotate:

In right-rotation, the arrangement of the nodes on the left is transformed into the arrangements on the right node.

Initial tree:



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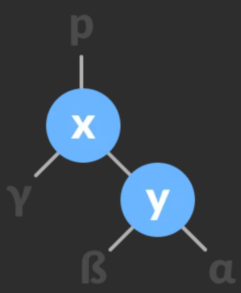
Right Rotate:



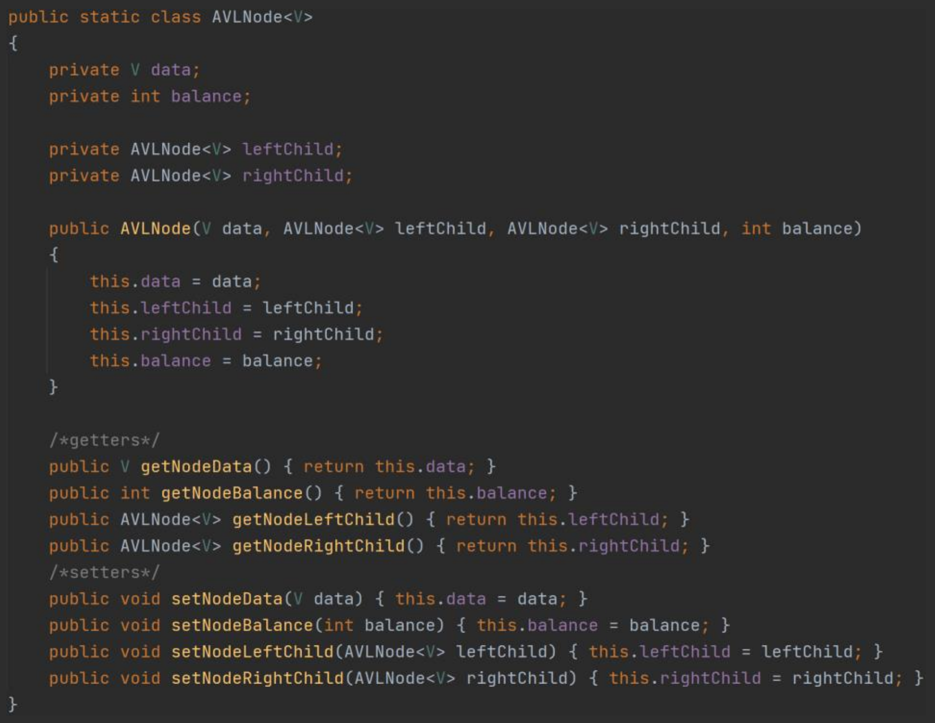
AVL Tree:

Memory usage: **O(n)**

Time complexity:

Function	Best case	Worst case
Insert	O(log(n))	O(log(n))
Search	O(log(n))	O(log(n))
Delete	O(log(n))	O(log(n))

Node structure:



```java
public static class AVLNode<V>
{
    private V data;
    private int balance;

    private AVLNode<V> leftChild;
    private AVLNode<V> rightChild;

    public AVLNode(V data, AVLNode<V> leftChild, AVLNode<V> rightChild, int balance)
    {
        this.data = data;
        this.leftChild = leftChild;
        this.rightChild = rightChild;
        this.balance = balance;
    }

    /*getters*/
    public V getNodeData() { return this.data; }
    public int getNodeBalance() { return this.balance; }
    public AVLNode<V> getNodeLeftChild() { return this.leftChild; }
    public AVLNode<V> getNodeRightChild() { return this.rightChild; }
    /*setters*/
    public void setNodeData(V data) { this.data = data; }
    public void setNodeBalance(int balance) { this.balance = balance; }
    public void setNodeLeftChild(AVLNode<V> leftChild) { this.leftChild = leftChild; }
    public void setNodeRightChild(AVLNode<V> rightChild) { this.rightChild = rightChild; }
}
```

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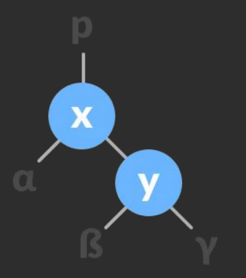
For balancing tree, we use such methods, like:

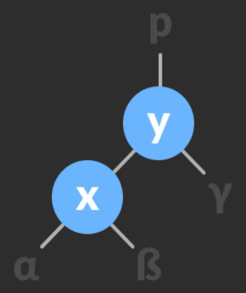
1. Left Rotate:

In left rotation, the arrangement of the nodes on the right is transformed into the arrangements on the left node.

Initial tree:



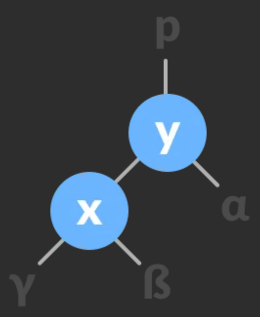
Left Rotate:



2. Right Rotate:

In right-rotation, the arrangement of the nodes on the left is transformed into the arrangements on the right node.

Initial tree:



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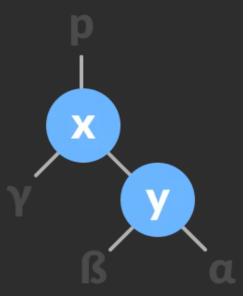
Right Rotate:



HashMap:

Memory usage: **O(n)**

Time complexity:

Function	Best case	Worst case
Insert	**O**(**1**)	**O**(**n**)
Search	**O**(**1**)	**O**(**n**)
Delete	**O**(**1**)	**O**(**n**)

A hash table is a data structure that associates keys with values. Hash tables provide constant time searches **O**(**1**) on average, regardless of the number of items in the table. But a rare worst case scenario can flat to **O**(**n**). Compared to other data structures, associative arrays are hash tables most useful for storing large amounts of data. Hash tables are much faster than self-balancing **BST**.

My hash function:

```
private int hash(K key)
{
    if(key == null)
        return 0;

    int h = key.hashCode();

    return h ^ (h >>> 16);
}
private int index(int hash) { return (capacity - 1) & hash; }
```

Collision resolutions:

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In my project I've used two types of collision resolutions, such as:

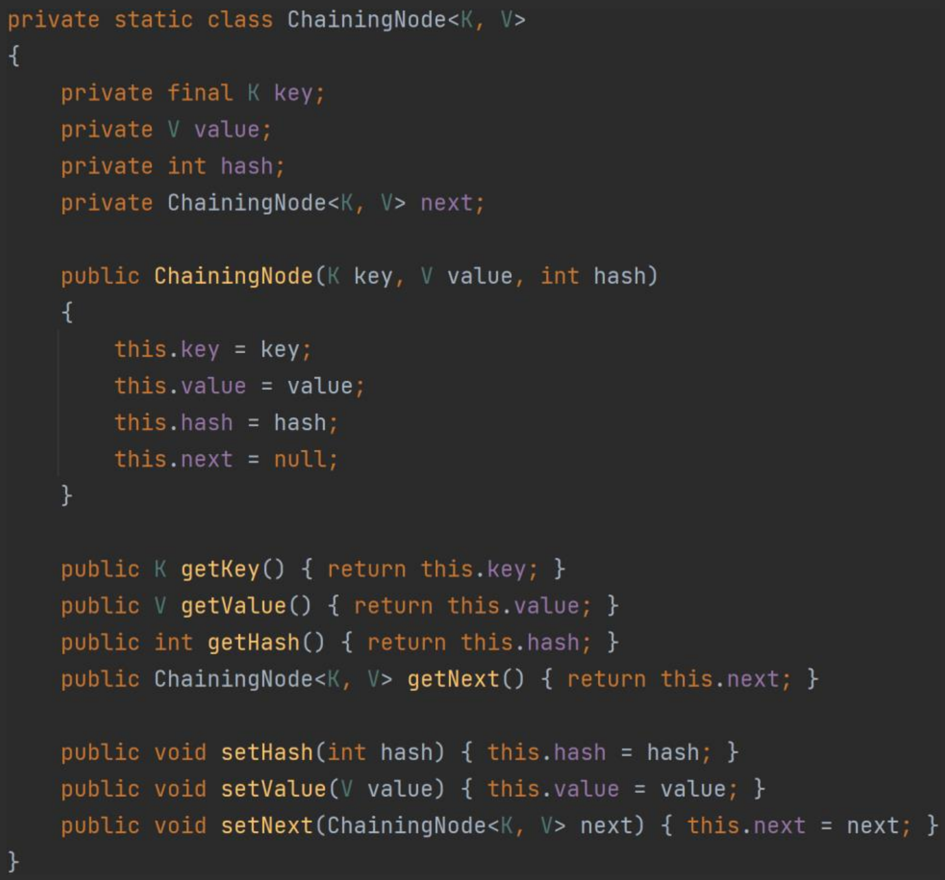
1. **Chaining method**
2. **Linear probing**

Chaining method:

Each cell of the array H is a pointer to a linked list (chain) of key-value pairs corresponding to the same key hash value. Collisions simply result in chains that are longer than one element.

Finding or deleting an element requires searching through all the elements of the corresponding chain to find an element with a given key in it. To add an element, you need to add an element to the end or the beginning of the corresponding list, and if the fill factor becomes too large, increase the size of the array **H** and rebuild the table.

Node structure:



```
private static class ChainingNode<K, V>
{
    private final K key;
    private V value;
    private int hash;
    private ChainingNode<K, V> next;

    public ChainingNode(K key, V value, int hash)
    {
        this.key = key;
        this.value = value;
        this.hash = hash;
        this.next = null;
    }

    public K getKey() { return this.key; }
    public V getValue() { return this.value; }
    public int getHash() { return this.hash; }
    public ChainingNode<K, V> getNext() { return this.next; }

    public void setHash(int hash) { this.hash = hash; }
    public void setValue(V value) { this.value = value; }
    public void setNext(ChainingNode<K, V> next) { this.next = next; }
}
```

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Linear probing:

The array H stores the key-value pairs themselves. The element insertion algorithm checks the cells of the array H in some order until the first free cell is found, in which the new element will be written. This ordering is computed on the fly, saving on memory for the pointers required in chained hash tables.

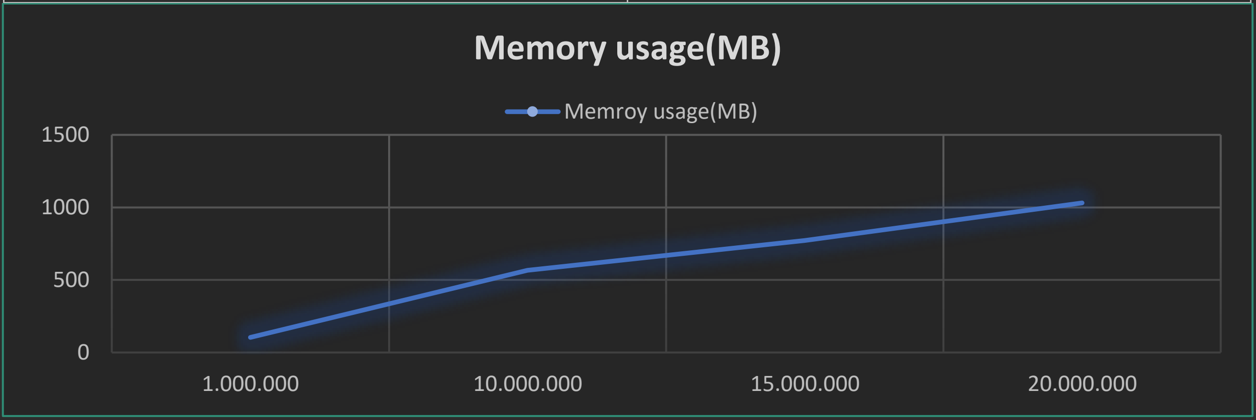
Time testing:

Every test have been done 100 times to find average time or memory usage.

Search test – I've been looking for number 31050405 which was at the end of BST or HashMap. The same I've done in Delete test.

Red-Black Tree:

Dataset	Memory usage(**MB**)
1.000.000	104
10.000.000	567
15.000.000	773
20.000.000	1031



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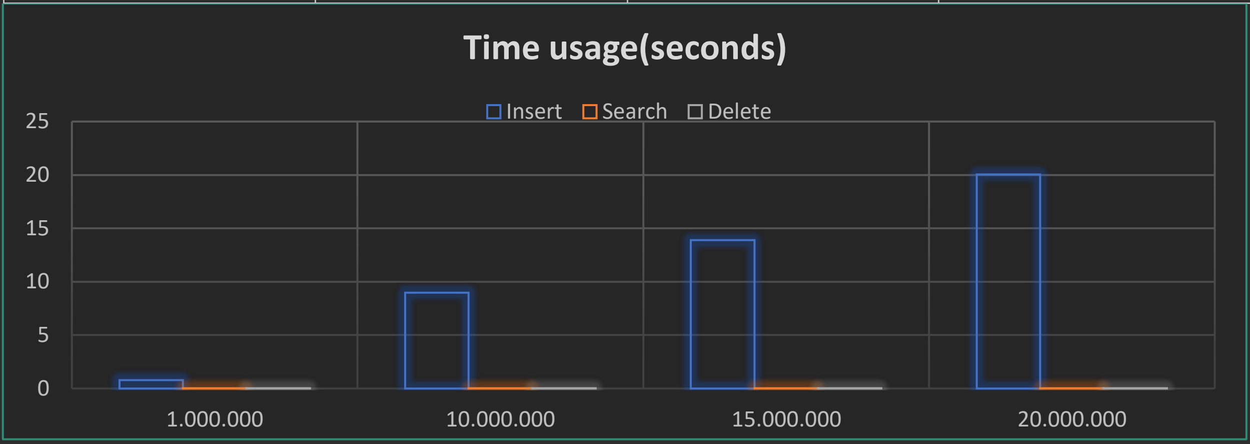
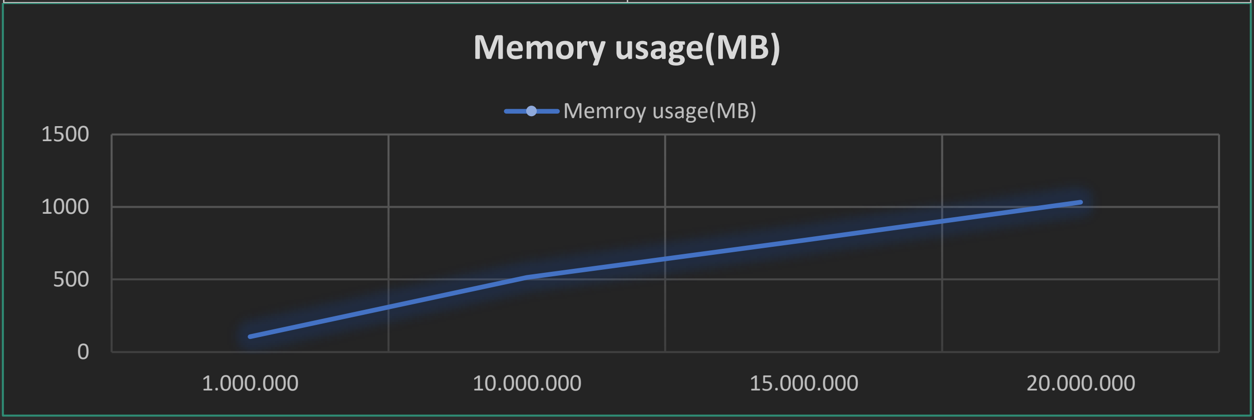
Dataset	Insert	Search	Delete
1.000.000	0,781	0,000025	0,00008
10.000.000	8,983	0,00003	0,000151
15.000.000	13,903	0,000023	0,000151
20.000.000	20,036	0,000029	0,000114



AVL Tree:

Dataset	Memory usage(MB)
1.000.000	106
10.000.000	514
15.000.000	770
20.000.000	1033



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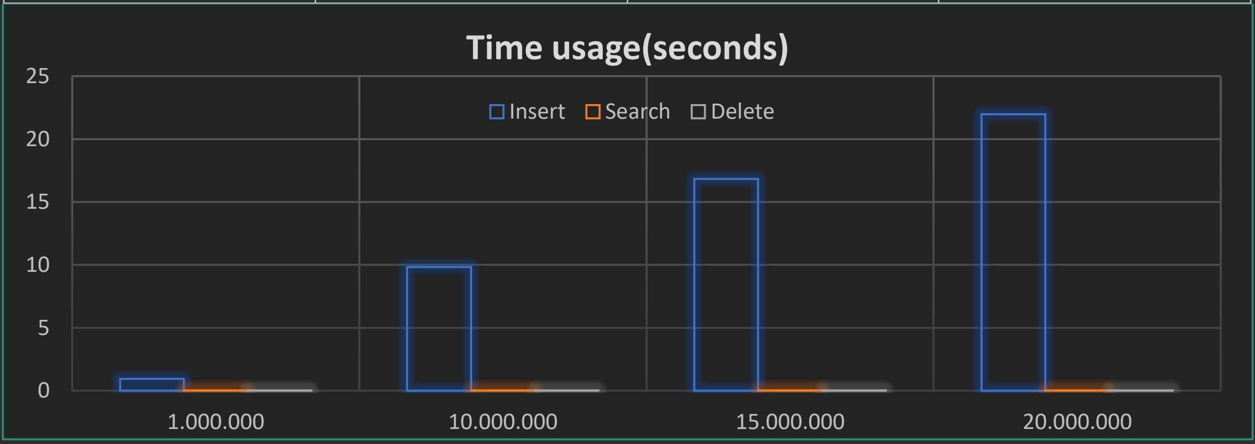
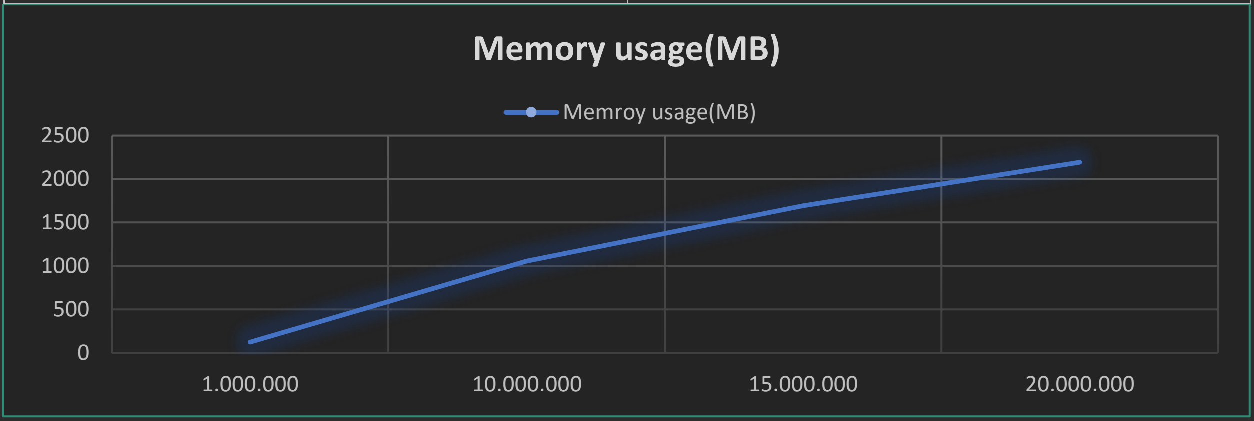
Dataset	Insert	Search	Delete
1.000.000	0,949	0,000027	0,000114
10.000.000	9,823	0,000021	0,000178
15.000.000	16,828	0,000024	0,000074
20.000.000	21,987	0,000015	0,000128



HashMap(Chaining):

Dataset	Memory usage(MB)
1.000.000	124
10.000.000	1057
15.000.000	1693
20.000.000	2193



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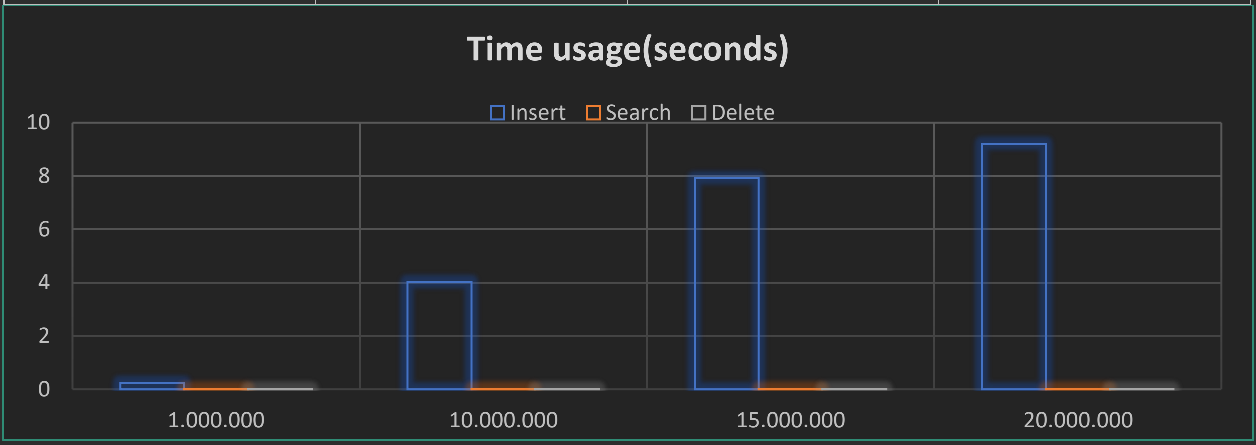
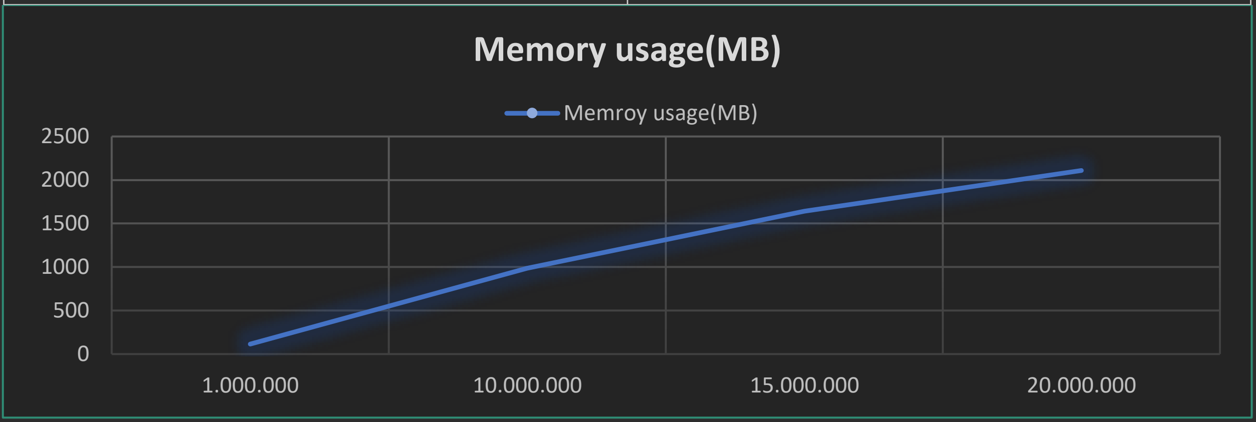
Dataset	Insert	Search	Delete
1.000.000	0,243	0,000012	0,000062
10.000.000	4,029	0,000012	0,000064
15.000.000	7,924	0,000008	0,000072
20.000.000	9,206	0,000004	0,000068



HashMap(Linear):

Dataset	Memory usage(**MB**)
1.000.000	115
10.000.000	986
15.000.000	1640
20.000.000	2109



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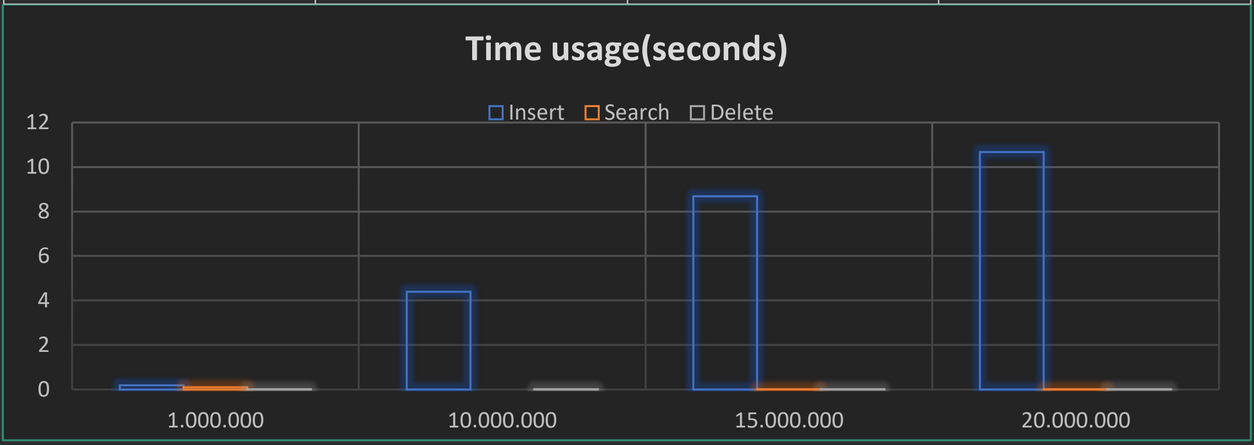
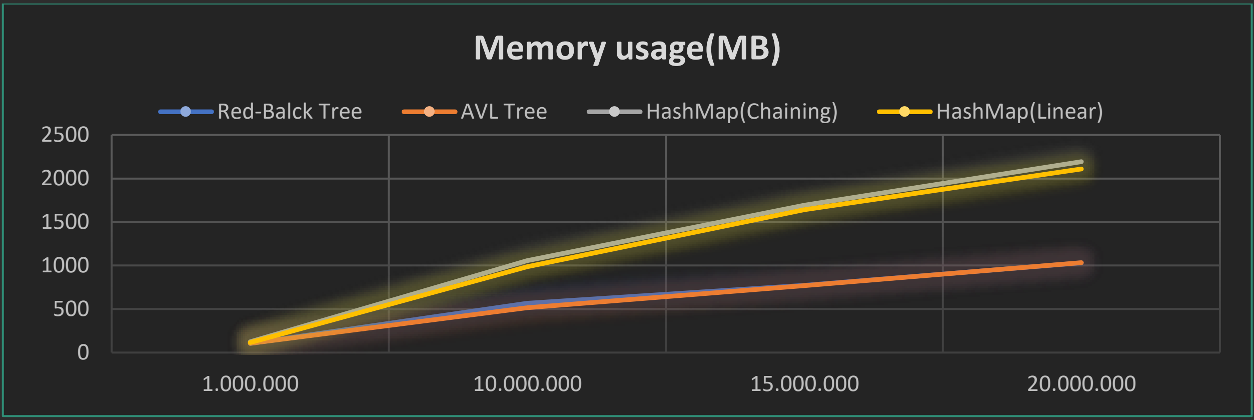
Dataset	Insert	Search	Delete
1.000.000	0,196	0,107657	0,007386
10.000.000	4,397	0,000004	0,000009
15.000.000	8,69	0,000005	0,000009
20.000.000	10,668	0,000061	0,000005



Comparison:

Dataset	RB Tree	AVL Tree	HashMap(Chain)	HashMap(Linear)
1.000.000	**104**	106	**124**	115
10.000.000	567	**514**	**1057**	986
15.000.000	773	**770**	**1693**	1640
20.000.000	**1031**	1033	**2193**	2109

Here we can see, that BST's use less memory than HashMap's.



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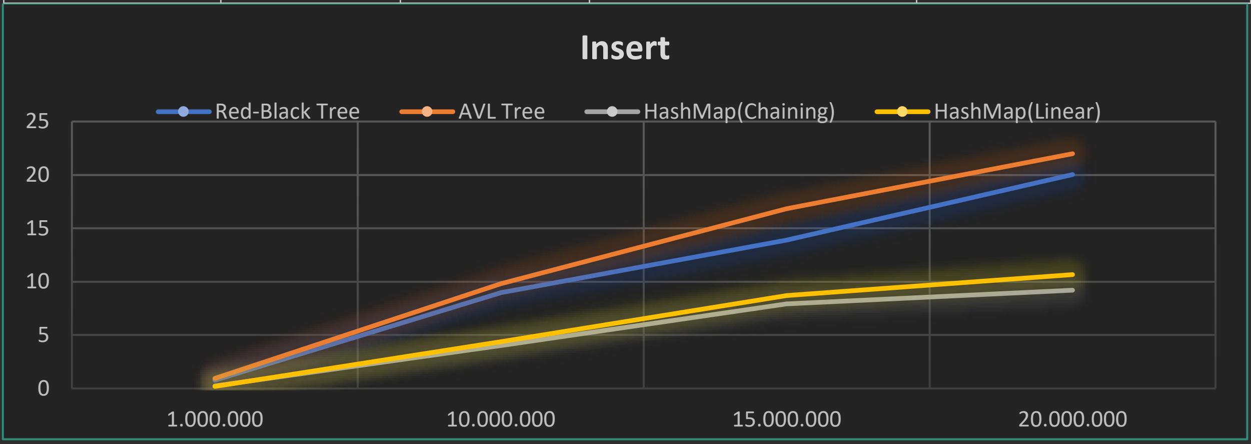
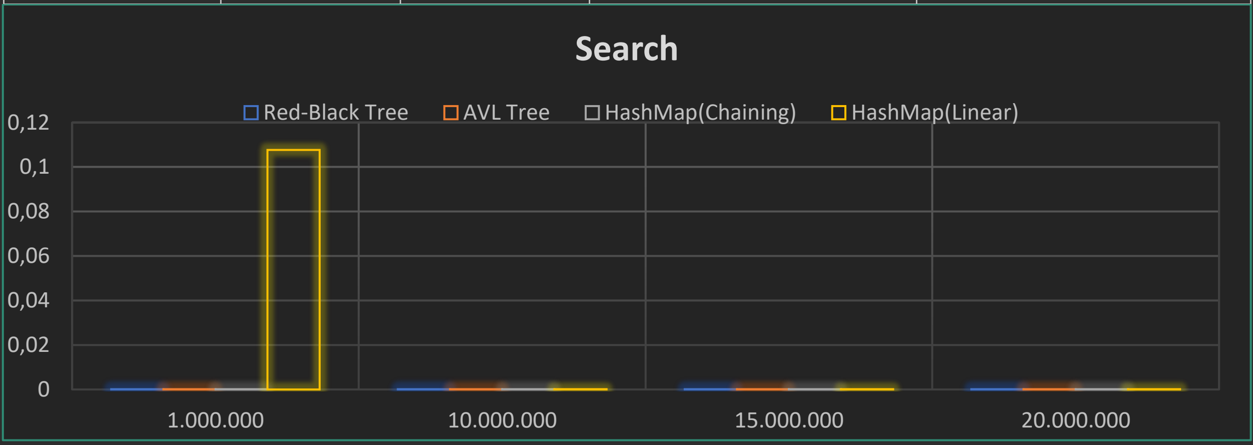
Dataset	RB Tree	AVL Tree	HashMap(Chain)	HashMap(Linear)
1.000.000	0,781	**0,949**	0,243	**0,196**
10.000.000	8,983	**9,823**	**4,029**	4,397
15.000.000	13,903	16,828	**7,924**	8,69
20.000.000	20,036	21,987	**9,206**	10,668



Dataset	RB Tree	AVL Tree	HashMap(Chain)	HashMap(Linear)
1.000.000	0,000025	0,000027	**0,000012**	**0,107657**
10.000.000	**0,00003**	0,000021	0,000012	**0,000004**
15.000.000	0,000023	**0,000024**	0,000008	**0,000005**
20.000.000	0,000029	0,000015	**0,000004**	**0,000061**



Dataset	RB Tree	AVL Tree	HashMap(Chain)	HashMap(Linear)
1.000.000	0,00008	0,000114	**0,000062**	**0,007386**
10.000.000	0,000151	**0,000178**	0,000064	**0,000009**
15.000.000	**0,000151**	0,000074	0,000072	**0,000009**
20.000.000	0,000114	**0,000128**	0,000068	**0,000005**

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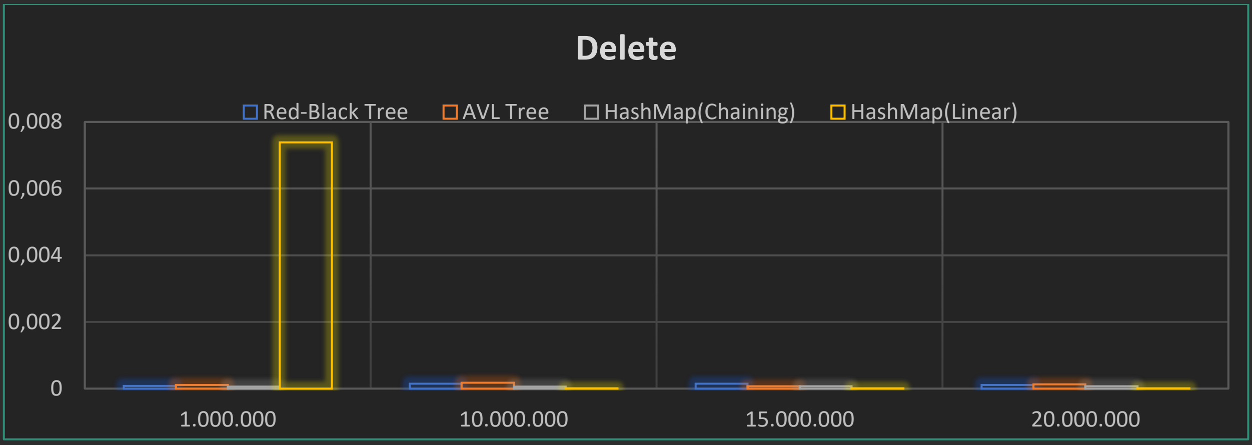

Conclusion:

A field of tests made sure that **Hash tables** are faster than **BSTs**, but **they take up much more memory**. **BSTs** are much **more stable**, they always stick to **O**(**log**(**n**)), table hashes can change from **O**(**1**) to **O**(**n**) in turn. I also realized that **the speed of code execution** also **depends on the input data**, this can be seen when comparing a data set for 1 million data and others. A dataset with 1 million values is much slower than other datasets.

If you need speed and the amount of memory consumed is not important for you, then your choice is the **Hash table**. If the amount of memory consumed is important to you - **BST**.