NANYANG TECHNOLOGICAL UNIVERSITY,

SCHOOL OF COMPUTER SCIENCE AND ENGINEERING

CZ4031 Database System Principles

Project 1

Group 41

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Base of B+ Tree Implementation	Wong Jing Yen
B+ Tree Implementation (Insertion)	Wong Jing Yen Kenny Tan Junrong Alloysius Lim Zong Hong Manimaran Manoj Kumar
B+ Tree Implementation (Search)	Wong Jing Yen Kenny Tan Junrong Manimaran Manoj Kumar
B+ Tree Implementation (Deletion)	Wong Jing Yen
Experiments	All members
Report	All members

Name	Contribution
Wong Jing Yen	20%
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Introduction

Description

This current project focuses on the design and implementation of the two components of a database management system, mainly storage and indexing. It also demonstrates a B+ Tree implementation that supports inserting, searching and deleting operations.

Project Overview

The implementation consists of the following classes with the corresponding responsibilities:

- Main.java: The boundary class that accepts user input and invokes methods in other classes to conduct the experiments for the project
- BPlusTreeNode.java: Implementation of the B+ Tree structure through insertion and deletion of keys into nodes. It also supports searching of keys.
- Disk.java: Supports insertion and deletion of records into blocks. Also supports retrieval of data from specified records from the disk.
- Block.java: Implementation of Block structure that controls the storage of records
- Record.java: Implementation of Record structure that holds the fields (tconst, averageRating, and numVotes).
- Utils.java: To map unchanging values to respective variable constants that are used throughout the classes that aids to make the code more robust.

Program Run Instructions

This program is built and compiled to a .jar file type to ensure the ease of running the program. The steps below are to run the .jar file from Terminal or IDE.

Clone the repository from Github repository https://github.com/kennytaan/CZ4031-DBSP-Java or extract the zipfile submitted. Ensure that you have any supporting Java IDE (E.g. Microsoft Visual Studios, Eclipse, IntelliJ) which may require additional installations like JDKs to open the project folder. A recommended installation guide is provided on README.md on github repository.

These are the following steps to run the program:

1. Navigate to the Main.java.file on IDE or Terminal (PATH: /CZ4031-DBSP-Java)
2. Running Main.java through the IDE or Terminal
3. Experiments 1-5 will be carried out with disk block size of 200MB and respective outputs can be seen under the Terminal after it has completed running.
4. The terminal will prompt for an user input to:
   - [1] Repeat Experiments 1-5 with disk block size of 500MB
   - [2] Exit the program
5. The program will continue to run only if “1” is entered, else it will prompt for the correct user input or exit the program.

6. Experiments 1-5 will be carried out with disk block size of 500MB and respective outputs can be seen under the Terminal after it has completed running.

Design of Storage components

Records

The data.tsv file consists of 3 column values: tconst, averageRating, numVotes.
Each line read from the tsv file is split into fields which are then packed into a single record as follows:

- tconst -> e.g. tt9916778 -> char[] (10characters with 2bytes each = 20bytes)
- averageRating -> e.g. 9.9 -> float (4 bytes)
- numVotes -> e.g. 4582 -> int (4 bytes)

Total record size = 28 bytes

```
byte[] tConst_b = stringToBytesUTFCustom(record.getTConst());
byte[] avgRating_b = floatToByteArray(record.getAverageRating());
byte[] numVotes_b = intToByteArray(record.getNumVotes());

ByteArrayOutputStream byteOutputStream = new ByteArrayOutputStream();
byteOutputStream.write(tConst_b);
byteOutputStream.write(avgRating_b);
byteOutputStream.write(numVotes_b);
byte[] record_b = byteOutputStream.toByteArray();
```

Figure 1: Logic to handle conversion of datatype to Byte Array

As show in Fig 1, each record attribute is being converted to a byte array to ensure consistency in data size. Thus, no additional memory is required to indicate the size of each field.

Blocks

```
public class Block {
    private byte[] data;
    private int blockOffset;
```

Figure 2: Block class

The class Block consist of 2 private declarations:

- data
  - o Consist of the data bytes of a single record
- blockOffset
  - o Acts as a pointer to determine the next location of the next record. The offset will be adjusted if a new block is created.

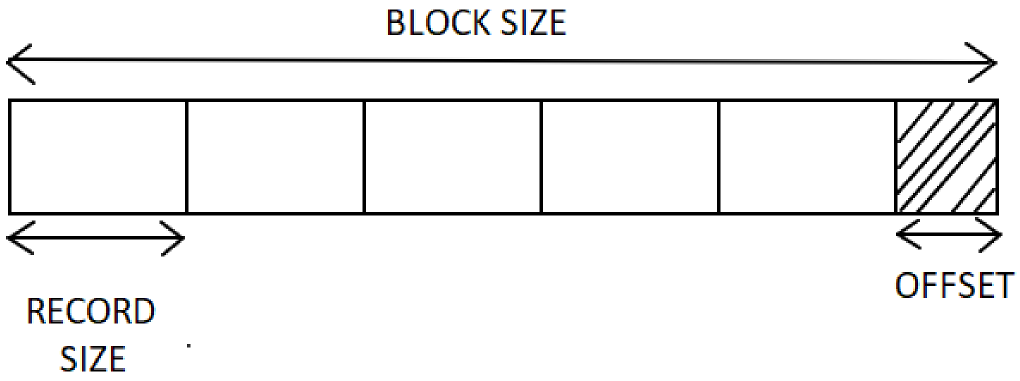

Figure 3: How records are packed into block

This project utilises the unspanned record method to pack records into blocks. This means that the record can only be stored inside a block if it can be completely stored into it. A record cannot be stored in more than one block. The reasons for choosing this method are as follows:

- Record size is smaller than block size.
- Access time of a record is much faster.
- It is a simpler way for storage implementation as compared to the spanned record method.

```
int offset;

if (blocks[currentBlock] == null) {
    blocks[currentBlock] = new Block();
}

if (blocks[currentBlock].getOffset() < (BLOCKSIZE - RECORDSIZE)) {
    offset = blocks[currentBlock].getOffset();
    blocks[currentBlock].addData(record_b);
} else {
    currentBlock++;
    blocks[currentBlock] = new Block();
    offset = blocks[currentBlock].getOffset();
    blocks[currentBlock].addData(record_b);
}
```

Figure 4: Logic to handle packing of records into a block

Fig 4 shows how we implement the part where the records can only be inserted into the block if its size is smaller than the offset. A new block will be created to store the record if the record’s size is greater than the offset and cannot be inserted into the block.

Disk Storage

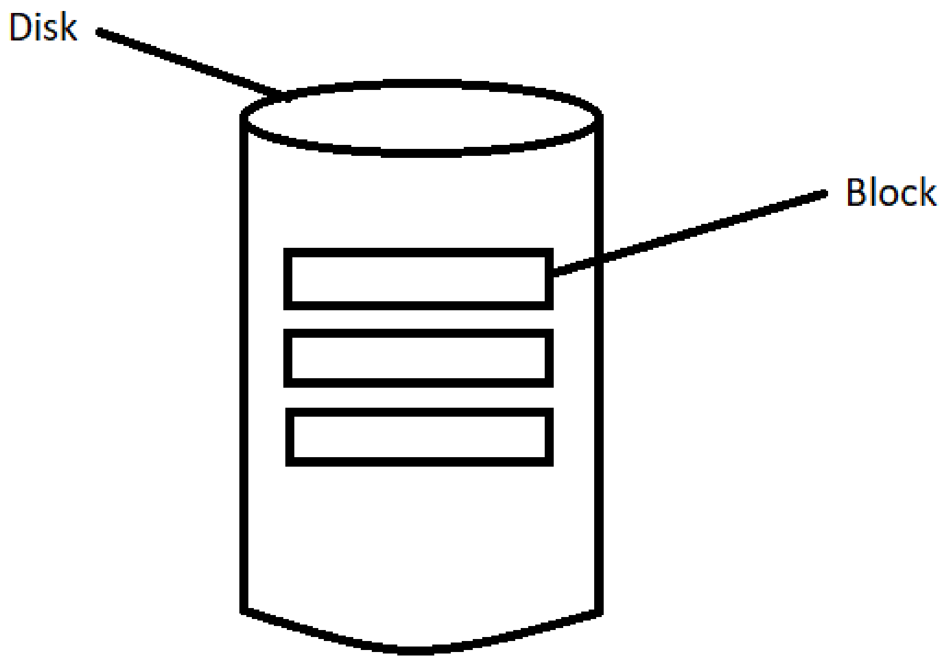

Figure 5: How blocks are stored in a disk

The blocks are then arranged sequentially on the disk to minimise seek and rotational delay.

```
//store blocks in an array
// to access certain block --> blocks[blockno]
private Block[] blocks;
private int currentBlock;
```

Figure 6: Block class

Similar to the diagram shown in Fig 5, Fig 6 shows how we implement the disk storage by using an array of Block objects to store the blocks and the index of the array represents the current block that we want to access. For e.g. when current block(int) = 4, blocks[4] allow us to access the 5th block in the disk.

Disk Operations

The disk is able to support several operations:

- Insert Record
- Delete Record
- Search Record
- Print Record

Design of B+ Tree Component

Data Structure of a node

```
private int[] keys = new int[NUMOFKEYS];
private Object[] pointers = new Object[NUMOFPOINTERS];
private int size = 0;
private int height = 0;
//private static int numOfDeletedMerged = 0;
```

Figure 7: Variables of a node

Every Node consists of the following variables:

- Keys
    - Integer Array of size (Bytes) that stores the (name) value
- Pointers
    - Object Array of size (Bytes) that stores pointers address of each child/sibling nodes or (name) value
- Size
    - Size of the node
- Height
    - Height of the B+ Tree

Maximum number of keys in which a Node maintains

```java
/*
BLOCKSIZE
n+1 pointers (8 Bytes)
n integer keys (4 Bytes)
BLOCKSIZE = 8n + 8 +4n
1 BLOCK can fit in (BLOCKSIZE-8/12) keys
 */
public static final int NUMOFKEYS = ((BLOCKSIZE-8)/12);

public static final int NUMOFPOINTERS= NUMOFKEYS+1;

public static final int MINKEYS =  (NUMOFKEYS+1)/2;
```

Figure 8: Functions in Utils.java

In Utils.java, functions are implemented to handle the calculation of values for respective variables. Fig 8 is how we calculate the number of keys, number of pointers and minimum number of keys in a node. As we know that the pointer size is 8bytes due to 64-bit processor and operating system, together with the key size which is 4 bytes for numVotes integer, we can know that every key-pointer pair will have a size of 12bytes in total. Hence, we are able to calculate the maximum number of keys that can be implemented in a node with regards to the block size. At the same time, we are also able to calculate the minimum number of keys in a leaf node with the formula which is the floor of (n+1)/2.

```java
public class BTreeNode {



    public static final int MAX_KEYS = NUMOFKEYS;
    private static final int MAX_POINTERS = NUMOFPOINTERS;
    private static final int MIN_KEYS = MINKEYS;
    private static final int MIN_NON_LEAF = NUMOFKEYS/2;
    private static int root = 0;
    private static int numOfNodes = 0;
```

Figure 9: Variables instantiated in BTreeNode class

With the values we get from Utils.java, the maximum number of keys (MAX_KEYS) can be fetched from it, which correlates to the size of the block.

- For a block size of 200B, MAX_KEYS will be ⌊ [(200 – 8) / (4 + 8)] ⌋ = 16
- For a block size of 500B, MAX_KEYS will be of ⌊ [(500 – 8) / (4 + 8)] ⌋ = 41

Building of B+ Tree

The implementation of B+ Tree is mostly done in BTreeNode.java. It supports the 3 main operations: Insert, Search and Delete.

Insertion

```
//only for leaf node
//insert a key and sort the node
public void insertKey(int key, Object pointer){
    for(int i=0;i<MAX_KEYS;i++){
        if(key < this.keys[i] || this.keys[i] == -1){
            for (int j=this.size;j>i;j--){
                this.keys[j] = this.keys[j-1];
                this.pointers[j] = this.pointers[j-1];
            }
            this.keys[i] = key;
            this.pointers[i] = pointer;
            this.size++;
            return;
        }
    }
}
```

Figure 10: Base logic to handle insertion of keys in leaf node

```
//only for non leaf node
//insert a key with both child pointers and sort the node
public void insertKey(int key, Object pointer1, Object pointer2){
    int i;
    for(i=0;i<this.size+1;i++){
        if(key < this.keys[i] || this.keys[i] == -1){
            for (int j=this.size;j>i;j--){
                this.keys[j] = this.keys[j-1];
                this.pointers[j + 1] = this.pointers[j];
                this.pointers[j] = this.pointers[j-1];
            }
            this.keys[i] = key;
            this.pointers[i] = pointer1;
            this.pointers[i+1] = pointer2;
            this.size++;
            break;
        }
    }
}
```

Figure 11:Base logic to handle insertion of keys in non-leaf node

Fig 10 and 11 shows the logic to handle insertion of key into both leaf and non-leaf nodes and to sort them after it is being inserted. By looping through the keys in the node, the new key inserted will be compared key by key. This is to check the actual position that it should be inserted within the node.

```
public BTreeNode insertLeafNode(int key, int address){
    // if node is not full insert key
    if (this.size < MAX_KEYS){
        this.insertKey(key, address);
        return this;
    }
    // node is full
    numOfNodes++;
    BTreeNode newLeaf = new BTreeNode();
    int newNodeSize=0;
    //split the node
    for(int i=MIN_KEYS;i<MAX_KEYS; i++){
        newLeaf.keys[newNodeSize] = this.keys[MIN_KEYS];
        newLeaf.pointers[newNodeSize] = this.pointers[MIN_KEYS];
        this.deleteLeafPointer(this.pointers[MIN_KEYS]);
        newNodeSize++;
    }
    newLeaf.size = newNodeSize; //new leaf is right node

    //insert key into corr node
    if (key < newLeaf.keys[0]){
        this.insertKey(key, address);
    }
    else{
        newLeaf.insertKey(key, address);
    }
    // check this.size == newLeaf.size  or this.size == newLeaf.size+1
    if (this.size < newLeaf.size){
        this.insertKey(newLeaf.keys[0], newLeaf.pointers[0]);
        newLeaf.deleteLeafPointer(newLeaf.pointers[0]);
    }
    else if(this.size> newLeaf.size+1){
        newLeaf.insertKey(this.keys[this.size-1], this.pointers[this.size-1]);
        this.deleteLeafPointer(this.pointers[this.size-1]);
    }
    // arrange last pointer
    newLeaf.pointers[MAX_KEYS] = this.pointers[MAX_KEYS];
    this.pointers[MAX_KEYS] = newLeaf;

    //return parent node
    BTreeNode parent = new BTreeNode();
    parent.insertKey(newLeaf.keys[0], this, newLeaf);
    parent.height = 1;
    if(this.root < parent.height) {
        this.root = parent.height;
        numOfNodes++;
    }
    return parent;
}
```

Figure 12: Logic to handle insertion of keys into leaf node

Fig 12 shows how we implement the insertion of keys into a leaf node. If the leaf node still has empty space for insertion, we will just insert the key into the directly insert the key into the leaf node and return the node.

However, if we know that the insertion will cause an overflow, we will split the node and insert the second half of the node into a corresponding new node. We will then compare and check whether the key should be inserted in the left node or the right node. After inserting the key into the correct node, we will create a new parent node which holds the value of the minimum key of the right node and return it.

```
//insert the key here
public BTreeNode insertNode(int key, int address){
    // if this is leaf
    if (this.height == 0){
        if(this.root == 0 && this.size == 0) numOfNodes++;
        return this.insertLeafNode(key, address);
    }
    // get child
    int childIndex = 0;
    for(int i=0;i<this.size && key >= this.keys[i]; i++){
        childIndex = i+1;
    }
    // this is a non leaf
    //insert to child
    BTreeNode child = (BTreeNode) this.pointers[childIndex];
    this.pointers[childIndex] = child.insertNode(key, address);
    // if same parent key is returned
    if (child == this.pointers[childIndex]){
        return this;
    }
    BTreeNode newParent = (BTreeNode) this.pointers[childIndex];
    // if current non leaf is not full
    if( this.size< MAX_KEYS){
        this.insertKey(newParent.keys[0], newParent.pointers[0], newParent.pointers[1]);
        return this;
    }
    // number of keys allocated to new right node
    int newNodeKeys = MAX_KEYS/2;
    int newNodePointers = newNodeKeys+1;
    // number of keys allocated to left node
    int oldNodeKeys = MAX_KEYS-newNodeKeys;
    int oldNodePointers = oldNodeKeys+1;
    int j=0;
    // copy all keys and pointers to one array
    BTreeNode[] childNodes = new BTreeNode[MAX_KEYS+2];
    for(int i=0; i<MAX_POINTERS;i++){
        if(i==childIndex){
            childNodes[j++] = (BTreeNode) newParent.pointers[0];
            childNodes[j++] = (BTreeNode) newParent.pointers[1];
            continue;
        }
        childNodes[j++] = (BTreeNode) this.pointers[i];
    }
```

Figure 13(i): Logic to handle insertion of keys into the B+ Tree (Part 1)

Fig 13(i) shows the first part of how we implement the insertion of keys into the B+ Tree. If we know that the tree is on the first level by checking the height, we know that it is a leaf node and call the insertion of keys into the leaf node as shown in Fig 12.

If it is not the first level, the function will retrieve the child nodes first and try to insert the keys into the child node with the same parents. The number of keys will be updated and allocated to the left node and the new right node. All the keys and pointers will then be copied into an array.

```java
        // initialise left non-leaf node
        // which we are going to reuse the current node
        this.pointers[0] = childNodes[0];
        for(int i=0; i<MAX_KEYS; i++){
            if(i < oldNodeKeys){
                this.keys[i] = findMin(childNodes[i+1]);
                this.pointers[i+1] = childNodes[i+1];
            }
            else{
                this.keys[i] =-1;
                this.pointers[i+1] = null;
            }
        }
        this.size = oldNodeKeys;

        //initialise right non-leaf node
        // we are going to create a new node for this
        BTreeNode newNonLeaf = new BTreeNode();
        newNonLeaf.height = this.height;
        newNonLeaf.size = newNodeKeys;
        newNonLeaf.pointers[0] = childNodes[oldNodePointers];
        for(int i=0; i<newNodeKeys; i++){
            newNonLeaf.keys[i] = findMin(childNodes[oldNodePointers+i+1]);
            newNonLeaf.pointers[i+1] = childNodes[oldNodePointers+i+1];
        }

        //new sibling node created add nodes
        numOfNodes++;

        //return parent node
        BTreeNode parent = new BTreeNode();
        parent.insertKey(findMin(childNodes[oldNodePointers]), this, newNonLeaf);
        parent.height = this.height +1;
        // if new root is created
        if (this.root< parent.height){
            this.root = parent.height;
            numOfNodes++;
        }
        return parent;
    }
```

Figure 13(ii): Logic to handle insertion of keys into B+ Tree (Part 2)

Searching

```java
public int[] search(int min, int max, boolean printNodes){
    // count number of access
    int count=0;
    if (printNodes){
        System.out.println(x: "Accessing nodes:");
    }
    ArrayList<Integer> result = new ArrayList<Integer>(Arrays.asList(-1));
    BTreeNode curNode;
```

Figure 14: Searching of leaf nodes (Declaration)

Fig 14 shows the logic to handle searching of both leaf and non-leaf nodes. Firstly, an ArrayList is declared in order to store the results and the BTreeNode is called instantiated in order to traverse down the B+ tree.

```java
int ptr=-1, i;
//get the min leaf node
curNode = this;
while(curNode.height>0){
    if(printNodes){
        //increment accesses
        count++;
        System.out.printf(curNode.getContent()+"\n");
    }
    ptr =0;
    for(i=0; i< curNode.size && min >= curNode.keys[i];i++){ // scan the node for child with key
        ptr = i+1;
    }
    if (i== curNode.size) ptr = curNode.size;
    curNode = (BTreeNode) curNode.pointers[ptr];
}
```

Figure 15: Searching of leaf nodes (Finding the leaf Node)

Fig 15 shows the continuation of the logic to handle searching of both leaf and non-leaf nodes. To traverse down the B+ tree, a loop is used against the height of the tree to recursively access the minimum leaf node. To ensure that the minimum leaf node is accessed, the count of the traversing is checked against the size of the current node.

```java
    while(curNode!=null){ // scan leaf nodes
        if(printNodes){
            count++;
            System.out.printf(curNode.getContent());
        }
        for(i=0;i< curNode.size;i++){
            if(curNode.keys[i] >= min && curNode.keys[i] <= max) { // if within range add to list
                if (result.get(index: 0) == -1) result.remove(index: 0);
                result.add((Integer) curNode.pointers[i]);
            }
            else if(curNode.keys[i] > max || curNode.keys[i] == -1){ //if max is reached
                if(printNodes)
                    System.out.println("Number of Nodes accessed: "+ count);
                return result.stream().mapToInt(num->num).toArray();
            }
        }
        curNode = (BTreeNode) curNode.pointers[MAX_KEYS]; // go to next node
        if(curNode == null){
            if (printNodes) System.out.println(x: "Reached end of database");
            else if (result.get(index: 0) == -1) System.out.println(x: "Key not found!");
        }
    }
    System.out.println("Number of Nodes accessed: "+ count);
    return result.stream().mapToInt(num->num).toArray();
}
```

Figure 16: Searching of leaf nodes (Finding the leaf Node)

Fig 16 shows the continuation of the logic to handle searching of both leaf and non-leaf nodes. While accessing the leaf nodes of the B+ tree, the key value of the leaf nodes are checked to see if it is within the range. If the values are indeed within the range of the leaf nodes, the key-value pair will be pushed into the ArrayList<result> and return as the output. If the values exceeds the maximum value of the leaf node, it will be redirected to access the subsequent leaf node until the value could be found within the list range. After all the leaf nodes have been accessed and if the values could not be found, search() will return a message to indicate the end of the database with no key found.

Deletion

```java
public BTreeNode remove(int key, ArrayList<BTreeNode> parents, ArrayList<Integer> parentPointer){
    BTreeNode curNode = this;
    int i=0;
    int ptr;
    // this gives me the leaf node
    while(curNode!=null) {
        while (curNode.height != 0) {

            //this gets the child position in parent
            // we need to check the node before to see if duplicates are there
            for (i = 0; i < curNode.size && key > curNode.keys[i]; i++) {
                continue;
            }
            //remember the parent node and the position f the child node in parent
            //treat this list as a stack
            parents.add( index: 0, curNode);
            parentPointer.add( index: 0, i);

            curNode = (BTreeNode) curNode.pointers[i];//child node with key
        }
        // find key and delete in leaf node
        boolean found = false;
        for (i = 0; i < curNode.size; i++) {
            if (curNode.keys[i] == key) {
                curNode.deleteLeafPointer(curNode.pointers[i]);
                found = true;
                break;
            }
        }

        if(found){
            break;
        }
        else {
            //get next node and update parents and pointer lists
            curNode = getNextNode(parents,parentPointer); //this the one , this line T-T
        }
    }
```

Figure 17: Remove of keys from leaf nodes (Instantiation & Removal)

Fig 17 shows the logic of the removal of leaf nodes. It requires the parameters of the specified key, a new arraylist in which stores BTreeNodes, and an array storing the subsequent pointers to key. If the key is found, it will then be successfully removed.

```java
if(curNode == null){
      System.out.println("not found");
    return this;
}

if(curNode == this){
    if(curNode.size == 0){
        System.out.println("Empty tree!");
    }
    return this;
}
// if the node from deletion has lesser than minimum keys
if( curNode.size < MIN_KEYS){
    BTreeNode parentNode = parents.get(0);
    int childIndex = parentPointer.get(0);

      parentPointer.remove(0);
    // check if left sibling exist
    if(childIndex-1 >= 0){
        BTreeNode leftSibling = (BTreeNode) parentNode.pointers[childIndex-1];
        // check if left sibling has enough keys
        if(leftSibling.size>MIN_KEYS){
            //take keys from sibling
            curNode.insertKey(leftSibling.keys[leftSibling.size-1], leftSibling.pointers[leftSibling.size-1]);
            leftSibling.deleteLeafPointer(leftSibling.pointers[leftSibling.size-1]);
            //update the parent keys
            parentNode.keys[childIndex-1] =  curNode.keys[0];
            return this;
        }
    }
    // check if right sibling exists
    if(childIndex+1 < parentNode.size+1){
        BTreeNode rightSibling = (BTreeNode) parentNode.pointers[childIndex+1];
        // check if right sibling has enough keys
        if(rightSibling.size>MIN_KEYS){
            curNode.insertKey(rightSibling.keys[0], rightSibling.pointers[0]);
            rightSibling.deleteLeafPointer(rightSibling.pointers[0]);
            // update the parents
```

Figure 18.1: Borrowing keys from siblings

```java
    // check if right sibling exists
    if(childIndex+1 < parentNode.size+1){
        BTreeNode rightSibling = (BTreeNode) parentNode.pointers[childIndex+1];
        // check if right sibling has enough keys
        if(rightSibling.size>MIN_KEYS){
            curNode.insertKey(rightSibling.keys[0], rightSibling.pointers[0]);
            rightSibling.deleteLeafPointer(rightSibling.pointers[0]);
            // update the parents
            parentNode.keys[childIndex] = rightSibling.keys[0];
            return this;
        }
    }
    // no siblings to get keys
    // attempt to merge with siblings
    //check if left sibling exists
    if(childIndex-1 >= 0){
        BTreeNode leftSibling = (BTreeNode) parentNode.pointers[childIndex-1];
        int j;
        for(i=leftSibling.size,j=0;j< curNode.size;j++,i++){
            leftSibling.keys[i] = curNode.keys[j];
            leftSibling.pointers[i] = curNode.pointers[j];
            leftSibling.size++;
        }
        // copy over last pointer
        leftSibling.pointers[MAX_POINTERS-1] = curNode.pointers[MAX_POINTERS-1];
          parentPointer.add(childIndex);
        BTreeNode result = removeInternal(parents, parentPointer);

        curNode.emptyALl();
        this.numOfNodes--;
        this.numOfDeleted++;
        if(result == this) return this;
        else{
            return result;
        }
    }
```

Figure 18.2: Remove of leaf nodes (Deletion & Combination of Left Sibling)

Fig 18.1 and 18.2 shows the continuation of the removal logic of leaf nodes. If the key is not found in the array list, an error message will be returned back to the user. An error message will also return back to the user if the user decides to remove a value from the empty tree. Once a node is removed, it has to be ensured that the size of the leaf nodes will be above the minimum threshold of the minimum key. If the number of nodes fall below the threshold, it will check if any left sibling nodes exist, move the keys from the sibling nodes and update the parent keys. The nodes will then be merged to the right sibling and the current node will copy over the last pointer.

```
    //merge right sibling if right sibling exists
    if(childIndex+1 < parentNode.size+1){

        BTreeNode rightSibling = (BTreeNode) parentNode.pointers[childIndex+1];

        int j;
        for(i=curNode.size,j=0;j< rightSibling.size;j++,i++){
            curNode.keys[i] = rightSibling.keys[j];
            curNode.pointers[i] = rightSibling.pointers[j];
            curNode.size++;
        }
        // copy over last pointer
        curNode.pointers[MAX_POINTERS-1] = rightSibling.pointers[MAX_POINTERS-1]
        parentPointer.remove( index: 0);
        parentPointer.add(childIndex+1);
        BTreeNode result = removeInternal(parents, parentPointer);
        rightSibling.emptyALL();
        this.numOfNodes--;
        this.numOfDeleted++;
        if(result == this) return this;
        else{
            return result;
        }
    }

}
return this;
```

Figure 19: Remove of leaf nodes (Combination of Right Sibling)

Fig 19 shows the continuation of the removal logic of leaf nodes. Once the left sibling node has been checked and verified, the steps taken are repeated for the right sibling node.

```java
public BTreeNode removeInternal( ArrayList<BTreeNode> parentList, ArrayList<Integer> pointerList){

    // get the parent node from the makeshift stack
    BTreeNode parent = parentList.get(0);
    parentList.remove( index: 0);

    // get the pointer index in parent node
    int parentPtr = pointerList.get(0);
    pointerList.remove( index: 0);
    //if the parent is the root and only 1 key
    //lets kill the root and take the child
    if(parent.height == this.root && parent.size == 1){
        this.root--;
        return (BTreeNode) parent.pointers[0];
    }
      System.out.println("CFM delete wrong");
      System.out.println(parentPtr);
    //remove the key from parent
    //shift all keys forward
    for(int j=parentPtr; j< parent.size-1;j++){
        parent.keys[j] = parent.keys[j+1];
        parent.pointers[j] = parent.pointers[j+1];
    }

    parent.pointers[parent.size-1] = parent.pointers[parent.size];
    parent.pointers[parent.size] = null;
    parent.keys[parentPtr-1] = findMin((BTreeNode) parent.pointers[parentPtr]);

    parent.keys[parent.size-1] = -1;
    parent.pointers[parent.size] = null;
    parent.size--;
```

Figure 20: Updating the non leaf/root nodes (Combination of Right Sibling)

removeInternal is a recursive function that is called every time leaf nodes are merged, this is to maintain consistency. It has the same implementation as figure 17, except it is for non-leaf nodes. It returns either a new root or the current root when returning to remove function.

Experiment Results

Experiment 1 Results

For Experiment 1, our team has stored the data on the disk and fetched the respective outputs:

1. Number of Blocks
2. Size of the Database (in terms of MB)

Block Size	Number Of Blocks	Database Size
200 B	152903	29.0 MB
500 B	62960	29.0 MB

```
EXPERIMENTS FOR 200MB
==================================================

Experiment 1:
The number of blocks: 152903
The size of database (in terms of MB): 29.0MB
```

Figure 21: Output for Experiment 1 for 200MB

```
EXPERIMENTS FOR 500MB
==================================================

Experiment 1:
The number of blocks: 62960
The size of database (in terms of MB): 29.0MB
```

Figure 22: Output for Experiment 1 for 500MB

Experiment 2 Results

For Experiment 2, our team has built the B+ tree based on the attribute “numVotes” by inserting the records sequentially and reported on the following statistics:

B+ Tree

1. Parameter ***n*** of B+ tree
2. Number of Nodes of B+ tree
3. Height of the B+ tree
4. Content of the root node and its 1st child node

B+ Tree				
Block Size	**n**	**Number Of Nodes**	**Height**	**Content for root node & 1st child node**
200 B	16	131514	6	Refer to Figure 23
500 B	41	51957	5	Refer to Figure 24

```
Experiment 2:
The parameter n of the B+ tree: 16
The number of nodes of the B+ tree: 131514
The height of the B+ tree, i.e the number of levels of the B+ tree: 6
The content of the root node:
Keys: [5, 7, 8, 10, 14, 18, 26, 41, 78, 198, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@3a71f4dd, MemoryPool.BTreeNode@7adf9f5f, MemoryPool.BTreeNode@85ede7b, MemoryPool.BTreeNode@5674cd4d, MemoryPool.BTreeNode@63961c42,


The content of the 1st child node:
Keys: [5, 5, 5, 5, 5, 5, 5, 5, -1, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@72ea2f77, MemoryPool.BTreeNode@33c7353a, MemoryPool.BTreeNode@681a9515, MemoryPool.BTreeNode@3af49f1c, MemoryPool.BTreeNode@19469ea2,
```

Figure 23: Experiment 2 output for block size 200MB

```
Experiment 2:
The parameter n of the B+ tree: 41
The number of nodes of the B+ tree: 51957
The height of the B+ tree, i.e the number of levels of the B+ tree: 5
The content of the root node:
Keys: [8, 17, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
Pointers: [MemoryPool.BTreeNode@46ee7fe8, MemoryPool.BTreeNode@7506e922, MemoryPool.BTreeNode@4ee285c6, null, null, null, null, null, null, null, null, null, nu


The content of the 1st child node:
Keys: [5, 5, 5, 5, 5, 5, 5, 6, 6, 6, 6, 6, 6, 6, 7, 7, 7, 7, 7, 7, 8, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@621be5d1, MemoryPool.BTreeNode@573fd745, MemoryPool.BTreeNode@15327b79, MemoryPool.BTreeNode@4f2410ac, MemoryPool.BTreeNode@722c41f4,
```

Figure 24: Experiment 2 output for blocksize 500MB

Experiment 3 Results

```
Experiment 3:
Accessing nodes:
Keys: [5, 7, 8, 10, 14, 18, 26, 41, 78, 198, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@3a71f4dd, MemoryPool.BTreeNode@7adf9f5f, MemoryPool.BTreeNode@85ede7b, MemoryPool.BTreeNode@5674cd4d, MemoryPool.BTreeNode@63961c42, MemoryPool.BTreeNode@65b54208, MemoryPool.BTreeNode@1be6f5c3,

Keys: [225, 259, 293, 337, 450, 646, 1021, 2101, 5251, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@1b28cdfa, MemoryPool.BTreeNode@eed1f14, MemoryPool.BTreeNode@7229724f, MemoryPool.BTreeNode@4c873330, MemoryPool.BTreeNode@119d7047, MemoryPool.BTreeNode@776ec8df, MemoryPool.BTreeNode@4eec7777,

Keys: [465, 481, 498, 508, 519, 530, 542, 553, 566, 578, 589, 600, 614, 631, -1, -1]
Pointers: [MemoryPool.BTreeNode@6d311334, MemoryPool.BTreeNode@682a0b20, MemoryPool.BTreeNode@3d075dc0, MemoryPool.BTreeNode@214c265e, MemoryPool.BTreeNode@448139f0, MemoryPool.BTreeNode@7cca494b, MemoryPool.BTreeNode@7ba4f24f,

Keys: [499, 500, 501, 502, 503, 504, 505, 506, 507, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@2d98a335, MemoryPool.BTreeNode@16b98e56, MemoryPool.BTreeNode@7ef20235, MemoryPool.BTreeNode@27d6c5e0, MemoryPool.BTreeNode@4f3f5b24, MemoryPool.BTreeNode@15aeb7ab, MemoryPool.BTreeNode@7b23ec81,

Keys: [499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@5b480cf9, MemoryPool.BTreeNode@6f496d9f, MemoryPool.BTreeNode@723279cf, MemoryPool.BTreeNode@10f87f48, MemoryPool.BTreeNode@b4c966a, MemoryPool.BTreeNode@2f4d3709, MemoryPool.BTreeNode@4e50df2e,

Keys: [499, 499, 499, 499, 499, 499, 499, 500, 500, 500, -1, -1, -1, -1, -1, -1]
Pointers: [27748856, 27875368, 28103600, 28193484, 28234568, 28515712, 29055456, 102712, 257656, 337884, null, null, null, null, null, null, MemoryPool.BTreeNode@12edcd21]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [650828, 776740, 778568, 876200, 908228, 945284, 1143000, 1308712, 1350968, null, null, null, null, null, null, null, MemoryPool.BTreeNode@34c45dca]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [1631568, 1645312, 1702340, 1827312, 2045568, 2082512, 2219168, 2516800, 2542168, null, null, null, null, null, null, null, MemoryPool.BTreeNode@52cc8049]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [2953656, 3151600, 3452856, 3857312, 3908940, 4838684, 5038828, 5191368, 5345484, null, null, null, null, null, null, null, MemoryPool.BTreeNode@5b6f7412]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [5350200, 6193856, 6494684, 6803284, 7535740, 7563228, 8069428, 8386284, 8453168, null, null, null, null, null, null, null, MemoryPool.BTreeNode@27973e9b]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [8453884, 8455256, 8456028, 8937456, 9071400, 9071684, 9170340, 10009228, 10045368, null, null, null, null, null, null, null, MemoryPool.BTreeNode@312b1dae]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [10887768, 14345684, 15219140, 15765940, 15910428, 15942940, 15967056, 16197968, 16678912, null, null, null, null, null, null, null, MemoryPool.BTreeNode@7530d0a]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [16791200, 16965568, 17084400, 17280568, 17319712, 17363740, 17534484, 17658256, 17750968, null, null, null, null, null, null, null, MemoryPool.BTreeNode@27bc2616]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [18367768, 19013084, 19784056, 19824028, 20240368, 20904968, 21075168, 21158112, 21677856, null, null, null, null, null, null, null, MemoryPool.BTreeNode@3941a79c]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [21810512, 21865800, 21928512, 21950740, 22172140, 22239456, 22537656, 22704200, 23107000, null, null, null, null, null, null, null, MemoryPool.BTreeNode@506e1b77]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [23264968, 23611940, 23823484, 23985400, 24191540, 24269656, 24326828, 24587112, 26386768, null, null, null, null, null, null, null, MemoryPool.BTreeNode@4fca772d]
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1]
Pointers: [26414000, 26686456, 26704940, 26833968, 27711256, 27741200, 28254228, 28282484, 28341284, null, null, null, null, null, null, null, MemoryPool.BTreeNode@9807454]
```

```
Number of Nodes accessed: 19
```

```
data block 1
       Record 0     tt0013674            7.0            500
       Record 1     tt0024561            6.8            500
       Record 2     tt0028277            7.7            500
       Record 3     tt0041956            6.5            500
       Record 4     tt0047361            7.3            500
       Record 5     tt0047434            6.3            500
       Record 6     tt0051500            5.1            500
data block 2
       Record 7     tt0052815            6.7            500
       Record 8     tt0054298            3.7            500
       Record 9     tt0062345            4.7            500
      Record 10     tt0069064            5.8            500
      Record 11     tt0070783            5.1            500
      Record 12     tt0082275            7.1            500
      Record 13     tt0082841            5.1            500
data block 3
      Record 14     tt0085198            7.0            500
      Record 15     tt0090356            3.8            500
      Record 16     tt0099259            6.0            500
      Record 17     tt0100811            5.3            500
      Record 18     tt0106600            4.8            500
      Record 19     tt0119415            4.6            500
      Record 20     tt0120462            4.5            500
data block 4
      Record 21     tt0149695            4.3            500
      Record 22     tt0163456            8.1            500
      Record 23     tt0184456            5.7            500
      Record 24     tt0214362            8.1            500
      Record 25     tt0218000            6.3            500
      Record 26     tt0289115            5.1            500
      Record 27     tt0303487            5.9            500
data block 5
      Record 28     tt0314564            2.9            500
      Record 29     tt0327085            5.5            500
      Record 30     tt0327546            6.4            500
      Record 31     tt0398451            6.5            500
      Record 32     tt0424365            5.5            500
      Record 33     tt0450955            3.9            500
      Record 34     tt0514442            9.1            500
The number of data blocks accessed is 110

Average of average rating: 6.731818214329806
```

Figure 25: Output for Experiment 3 for 200MB

```
Experiment 3:
Accessing nodes:
Keys: [8, 17, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
Pointers: [MemoryPool.BTreeNode@46ee7fe8, MemoryPool.BTreeNode@7506e922, MemoryPool.BTreeNode@4ee285c6, null, null, null, null, null, null, null, null, null, null, nu

Keys: [18, 19, 20, 21, 22, 23, 24, 26, 28, 30, 31, 33, 35, 37, 39, 42, 47, 51, 56, 61, 68, 73, 79, 88, 97, 107, 119, 146, 180, 228, 302, 395, 540, 819, 1283, 2334, -
Pointers: [MemoryPool.BTreeNode@20fa23c1, MemoryPool.BTreeNode@3581c5f3, MemoryPool.BTreeNode@6aa8ceb6, MemoryPool.BTreeNode@2530c12, MemoryPool.BTreeNode@73c6c3b2,

Keys: [400, 405, 410, 415, 419, 424, 430, 435, 442, 445, 449, 455, 461, 466, 472, 479, 486, 494, 502, 510, 517, 524, 531, 535, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1
Pointers: [MemoryPool.BTreeNode@1c655221, MemoryPool.BTreeNode@58d25a40, MemoryPool.BTreeNode@1b701da1, MemoryPool.BTreeNode@726f3b58, MemoryPool.BTreeNode@442d9b6e,

Keys: [494, 494, 494, 494, 495, 495, 495, 495, 495, 496, 496, 496, 496, 496, 497, 497, 497, 497, 497, 498, 498, 498, 498, 498, 499, 499, 499, 499, 499, 500, 500, 500
Pointers: [MemoryPool.BTreeNode@5e91993f, MemoryPool.BTreeNode@1c4af82c, MemoryPool.BTreeNode@379619aa, MemoryPool.BTreeNode@cac736f, MemoryPool.BTreeNode@5e265ba4,

Keys: [499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 499, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1
Pointers: [22957392, 23217140, 23535084, 23909724, 24160892, 24703864, 25761308, 25993000, 26577000, 26609808, 27102168, 27431752, 27727612, 28006584, 28262724, 2851
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -
Pointers: [801448, 901948, 934920, 973084, 1176612, 1347196, 1390696, 1679556, 1693696, 1752392, 1881056, 2105724, 2143752, 2284420, 2590808, 2616920, 3040528, 3244
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -
Pointers: [4981000, 5187028, 5344056, 5502696, 5507556, 6376028, 6685696, 7003364, 7757364, 7785668, 8306752, 8632920, 8701780, 8702528, 8703920, 8704724, 9200308, 9
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -
Pointers: [10340808, 11208000, 14767612, 15666752, 16229640, 16378364, 16411836, 16436668, 16674364, 17169448, 17285056, 17464556, 17586864, 17788808, 17829112, 1787
Keys: [500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, 500, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -
Pointers: [20365920, 20407084, 20835668, 21519808, 21695028, 21780392, 22315420, 22452000, 22508892, 22573448, 22596336, 22824252, 22893556, 23200528, 23371948, 2378
```

```
Number of Nodes accessed: 10
```

```
The content of data blocks accessed:
data block 1
       Record 0     tt0013674          7.0          500
       Record 1     tt0024561          6.8          500
       Record 2     tt0028277          7.7          500
       Record 3     tt0041956          6.5          500
       Record 4     tt0047361          7.3          500
       Record 5     tt0047434          6.3          500
       Record 6     tt0051500          5.1          500
       Record 7     tt0052815          6.7          500
       Record 8     tt0054298          3.7          500
       Record 9     tt0062345          4.7          500
      Record 10     tt0069064          5.8          500
      Record 11     tt0070783          5.1          500
      Record 12     tt0082275          7.1          500
      Record 13     tt0082841          5.1          500
      Record 14     tt0085198          7.0          500
      Record 15     tt0090356          3.8          500
      Record 16     tt0099259          6.0          500
```

```
data block 2
      Record 17     tt0100811          5.3          500
      Record 18     tt0106600          4.8          500
      Record 19     tt0119415          4.6          500
      Record 20     tt0120462          4.5          500
      Record 21     tt0149695          4.3          500
      Record 22     tt0163456          8.1          500
      Record 23     tt0184456          5.7          500
      Record 24     tt0214362          8.1          500
      Record 25     tt0218000          6.3          500
      Record 26     tt0289115          5.1          500
      Record 27     tt0303487          5.9          500
      Record 28     tt0314564          2.9          500
      Record 29     tt0327085          5.5          500
      Record 30     tt0327546          6.4          500
      Record 31     tt0398451          6.5          500
      Record 32     tt0424365          5.5          500
      Record 33     tt0450955          3.9          500
```

```
data block 3
      Record 34     tt0514442             9.1             500
      Record 35     tt0517623             8.1             500
      Record 36     tt0558715             8.1             500
      Record 37     tt0582480             8.3             500
      Record 38     tt0588114             8.7             500
      Record 39     tt0588139             8.1             500
      Record 40     tt0588187             8.2             500
      Record 41     tt0588214             8.6             500
      Record 42     tt0629708             8.1             500
      Record 43     tt0640298             8.0             500
      Record 44     tt0640308             8.2             500
      Record 45     tt0647512             7.2             500
      Record 46     tt0716912             7.6             500
      Record 47     tt0720140             7.1             500
      Record 48     tt0807689             8.6             500
      Record 49     tt11691696            6.4             500
      Record 50     tt1261908             8.1             500
```

```
data block 4
	Record 51	tt1340802		6.0		500
	Record 52	tt1365490		6.5		500
	Record 53	tt1371697		7.9		500
	Record 54	tt1376451		5.9		500
	Record 55	tt1421383		7.6		500
	Record 56	tt1515736		7.5		500
	Record 57	tt1535989		6.4		500
	Record 58	tt1571100		5.9		500
	Record 59	tt1592534		6.6		500
	Record 60	tt1632756		7.4		500
	Record 61	tt1640740		7.7		500
	Record 62	tt1648683		7.5		500
	Record 63	tt1684558		5.3		500
	Record 64	tt1711021		6.2		500
	Record 65	tt1727519		4.1		500
	Record 66	tt1857596		7.8		500
	Record 67	tt2040651		7.8		500
```

```
data block 5
	Record 68	tt2236257		7.4		500
	Record 69	tt2247719		7.7		500
	Record 70	tt2365211		8.1		500
	Record 71	tt2662228		6.6		500
	Record 72	tt2764038		8.3		500
	Record 73	tt2813064		5.6		500
	Record 74	tt3127434		8.1		500
	Record 75	tt3203366		8.2		500
	Record 76	tt3231390		3.6		500
	Record 77	tt3263598		7.3		500
	Record 78	tt3276280		8.3		500
	Record 79	tt3398808		5.5		500
	Record 80	tt3440780		7.1		500
	Record 81	tt3592904		2.3		500
	Record 82	tt3683072		6.0		500
	Record 83	tt3916858		7.8		500
	Record 84	tt4038966		6.4		500
The number of data blocks accessed is 110

Average of average rating: 6.731818214329806
```

Figure 26: Output for Experiment 3 for 500MB

For experiment 3, we have to retrieve those movies with the "numVotes" equal to 500 and report the following statistics:

1. Number and Content of index nodes the process accesses
2. Number and Content of data blocks the process accesses
3. Average of "averageRating's" of the records that are returned

		Block Size	
		200 B	500 B
Index Nodes Accessed	**Number**	19	10
	Content of index nodes and data blocks	Refer to the outputs in Figure 25	Refer to the outputs in Figure 26
Data Blocks Accessed	**Number**	110	110
	Content of index nodes and data blocks	Refer to outputs in the Figure 25	Refer to the outputs in Figure 26
Average of "averageRating's" of Records Returned		6.731818214329806	6.731818214329806

Experiment 4 Results

For experiment 4, our team has retrieved the movies with the attribute "numVotes" from 30,000 to 40,000, both inclusively and reported the following statistics:

1. Number and Content of index nodes the process accesses
2. Number and Content of data blocks the process accesses
3. Average of "averageRating's" of the records that are returned

		Block Size	
		200 B	500 B
Index Nodes Accessed	**Number**	91	38
	Content	Refer to outputs in Figure 27	Refer to outputs in Figure 28
Data Blocks Accessed	**Number**	942	930
	Content	Refer to outputs in Figure 27	Refer to outputs in Figure 28
Average of "averageRating's" of Records Returned		6.727911862221244	6.727911862221244

```
Experiment 4:
Accessing nodes:
Keys: [5, 7, 8, 10, 14, 18, 26, 41, 78, 198, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@3a71f4dd, MemoryPool.BTreeNode@7adf9f5f, MemoryPool.BTreeNode@85ede7b, MemoryPool.BTreeNode@5674cd4d, MemoryPool.BTreeNode@63961c42, Me

Keys: [225, 259, 293, 337, 450, 646, 1021, 2101, 5251, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@1b28cdfa, MemoryPool.BTreeNode@eed1f14, MemoryPool.BTreeNode@7229724f, MemoryPool.BTreeNode@4c873330, MemoryPool.BTreeNode@119d7047, Me

Keys: [6476, 8078, 10030, 12685, 16036, 20151, 32012, 54807, 117029, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@7e6cbb7a, MemoryPool.BTreeNode@7c3df479, MemoryPool.BTreeNode@7106e68e, MemoryPool.BTreeNode@7eda2dbb, MemoryPool.BTreeNode@6576fe71, M

Keys: [20697, 21313, 22002, 22703, 23360, 24128, 24833, 25682, 26715, 27668, 28769, 30034, 30902, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@2e817b38, MemoryPool.BTreeNode@c4437c4, MemoryPool.BTreeNode@433c675d, MemoryPool.BTreeNode@3f91beef, MemoryPool.BTreeNode@1a6c5a9e, Me

Keys: [28916, 29004, 29116, 29268, 29387, 29594, 29633, 29743, 29848, 29959, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@1d56ce6a, MemoryPool.BTreeNode@5197848c, MemoryPool.BTreeNode@17f052a3, MemoryPool.BTreeNode@2e0fa5d3, MemoryPool.BTreeNode@5010be6, Me

Keys: [29959, 29962, 29974, 29975, 29975, 29978, 29982, 29988, 29996, 30022, -1, -1, -1, -1, -1, -1]
Pointers: [20381340, 6700600, 2714084, 17457800, 22671056, 4787400, 24635712, 23120168, 20097028, 941940, null, null, null, null, null, null, MemoryPool.BTreeNode@7289
Keys: [30034, 30037, 30041, 30049, 30053, 30056, 30078, 30078, 30081, 30085, 30090, -1, -1, -1, -1, -1]
Pointers: [304340, 1862828, 22108256, 16370856, 2309200, 2196340, 4394968, 7237656, 20013256, 18977168, 1544628, null, null, null, null, null, MemoryPool.BTreeNode@21b
Keys: [30136, 30144, 30149, 30158, 30158, 30168, 30175, 30177, 30195, 30206, 30221, 30240, -1, -1, -1, -1]
Pointers: [11366140, 16267000, 20983456, 2256768, 4539368, 29908340, 29629456, 1638140, 17824140, 21698656, 1626968, 2373940, null, null, null, null, MemoryPool.BTreeN
Keys: [30246, 30247, 30248, 30254, 30259, 30262, 30275, 30319, 30326, 30333, 30341, 30354, 30361, 30370, -1, -1]
Pointers: [990000, 23826568, 28529884, 546740, 3738712, 5914368, 6406312, 14408940, 22145940, 11561084, 2196684, 6678684, 17265056, 13516828, null, null, MemoryPool.BT
Keys: [30376, 30391, 30395, 30402, 30418, 30423, 30431, 30446, 30453, 30456, 30457, 30458, 30462, -1, -1, -1]
Pointers: [7152028, 6314656, 17478800, 1063056, 23664912, 7191540, 22442856, 2259028, 29094428, 16594400, 1840428, 1881656, 2086856, null, null, null, MemoryPool.BTree
```

```
Number of Nodes accessed: 91
```

```
data block 1
       Record 0     tt0054167          7.7          30022
       Record 1     tt0026778          7.9          30034
       Record 2     tt0091828          5.6          30037
       Record 3     tt3361792          6.8          30041
       Record 4     tt1456941          6.2          30049
       Record 5     tt0110443          6.3          30053
       Record 6     tt0105629          5.1          30056
data block 2
       Record 7     tt0257516          5.0          30078
       Record 8     tt0489664          6.7          30078
       Record 9     tt2303687          8.7          30081
      Record 10     tt2027128          7.5          30085
      Record 11     tt0078718          7.4          30090
      Record 12     tt0857265          6.5          30136
      Record 13     tt1435513          6.7          30144
data block 3
      Record 14     tt2712740          8.1          30149
      Record 15     tt0108211          7.5          30158
      Record 16     tt0268397          6.0          30158
      Record 17     tt9053874          6.0          30168
      Record 18     tt8758202          7.5          30175
      Record 19     tt0082533          6.6          30177
      Record 20     tt1741256          7.2          30195
data block 4
      Record 21     tt3139086          7.5          30206
      Record 22     tt0082089          7.4          30221
      Record 23     tt0113253          4.9          30240
      Record 24     tt0056111          8.1          30246
      Record 25     tt4396630          7.4          30247
      Record 26     tt7668518          6.8          30248
      Record 27     tt0037382          7.8          30254
data block 5
      Record 28     tt0204993          7.4          30259
      Record 29     tt0377091          7.2          30262
      Record 30     tt0417001          5.9          30275
      Record 31     tt1174730          7.4          30319
      Record 32     tt3385524          7.2          30326
      Record 33     tt0880502          7.8          30333
      Record 34     tt0105643          2.9          30341
The number of data blocks accessed is 942

Average of average rating: 6.727911862221244
```

Figure 27: Output for Experiment 4 for 200MB

```
Experiment 4:
Accessing nodes:
Keys: [8, 17, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
Pointers: [MemoryPool.BTreeNode@46ee7fe8, MemoryPool.BTreeNode@7506e922, MemoryPool.BTreeNode@4ee285c6, null, null, null, null, null, null, null, null, null, null, n

Keys: [18, 19, 20, 21, 22, 23, 24, 26, 28, 30, 31, 33, 35, 37, 39, 42, 47, 51, 56, 61, 68, 73, 79, 88, 97, 107, 119, 146, 180, 228, 302, 395, 540, 819, 1283, 2334, -
Pointers: [MemoryPool.BTreeNode@20fa23c1, MemoryPool.BTreeNode@3581c5f3, MemoryPool.BTreeNode@6aa8ceb6, MemoryPool.BTreeNode@2530c12, MemoryPool.BTreeNode@73c6c3b2,

Keys: [2434, 2537, 2643, 2775, 2921, 3076, 3229, 3404, 3607, 3810, 4021, 4269, 4599, 5007, 5449, 5951, 6702, 7559, 8673, 10056, 12116, 14249, 17079, 20832, 25071, 30
Pointers: [MemoryPool.BTreeNode@5680a178, MemoryPool.BTreeNode@5fdef03a, MemoryPool.BTreeNode@3b22cdd0, MemoryPool.BTreeNode@1e81f4dc, MemoryPool.BTreeNode@4d591d15,

Keys: [25435, 25580, 25810, 25970, 26149, 26322, 26582, 26868, 27079, 27245, 27444, 27677, 27977, 28171, 28422, 28622, 28962, 29221, 29549, 29818, -1, -1, -1, -1, -1
Pointers: [MemoryPool.BTreeNode@4cc77c2e, MemoryPool.BTreeNode@7a7b0070, MemoryPool.BTreeNode@39a054a5, MemoryPool.BTreeNode@71bc1ae4, MemoryPool.BTreeNode@6ed3ef1,

Keys: [29818, 29819, 29823, 29824, 29828, 29834, 29848, 29861, 29869, 29876, 29880, 29882, 29900, 29910, 29919, 29949, 29954, 29956, 29956, 29959, 29962, 29974, 2997
Pointers: [4921140, 11555336, 25815112, 21786252, 15136392, 31326196, 1269084, 29294500, 22558528, 16778556, 6237224, 19837308, 30176028, 641500, 2488948, 24200500,
Keys: [30090, 30136, 30144, 30149, 30158, 30158, 30168, 30175, 30177, 30195, 30206, 30221, 30240, 30246, 30247, 30248, 30254, 30259, 30262, 30275, 30319, 30326, 3033
Pointers: [1590056, 11700420, 16745420, 21600612, 2323140, 4672864, 30788000, 30500892, 1686308, 18348364, 22336836, 1674808, 2443752, 1019112, 24527336, 29369000, 5
Keys: [30423, 30431, 30446, 30453, 30456, 30457, 30458, 30462, 30468, 30492, 30516, 30522, 30530, 30540, 30547, 30548, 30550, 30552, 30554, 30569, 30569, 30571, 3057
Pointers: [7403056, 23102920, 2325448, 29950140, 17082448, 1894556, 1937000, 2148224, 1834640, 2248448, 1135364, 12036112, 11589308, 2092668, 7335336, 20570420, 1797
Keys: [30658, 30658, 30661, 30669, 30672, 30673, 30674, 30677, 30693, 30697, 30699, 30705, 30714, 30715, 30726, 30737, 30755, 30755, 30766, 30766, 30769, 30770, 3077
Pointers: [951920, 16419920, 19769028, 1951280, 2379196, 11161196, 6111252, 1789364, 23470528, 19319864, 20280724, 1881892, 17448584, 6630448, 28226224, 23873112, 21
Keys: [30883, 30888, 30902, 30904, 30927, 30928, 30940, 30948, 30953, 30957, 30957, 30959, 30982, 30987, 30989, 30992, 30992, 31006, 31017, 31034, 31048, 31069, 3107
Pointers: [1202364, 1685640, 2499696, 1968392, 19757612, 6691920, 2095196, 20525084, 17836336, 2383668, 5923668, 12505224, 23178892, 2481556, 1991836, 2064808, 74545
```

```
Number of Nodes accessed: 38
```

```
data block 1
       Record 0     tt0054167          7.7          30022
       Record 1     tt0026778          7.9          30034
       Record 2     tt0091828          5.6          30037
       Record 3     tt3361792          6.8          30041
       Record 4     tt1456941          6.2          30049
       Record 5     tt0110443          6.3          30053
       Record 6     tt0105629          5.1          30056
       Record 7     tt0257516          5.0          30078
       Record 8     tt0489664          6.7          30078
       Record 9     tt2303687          8.7          30081
      Record 10     tt2027128          7.5          30085
      Record 11     tt0078718          7.4          30090
      Record 12     tt0857265          6.5          30136
      Record 13     tt1435513          6.7          30144
      Record 14     tt2712740          8.1          30149
      Record 15     tt0108211          7.5          30158
      Record 16     tt0268397          6.0          30158
data block 2
      Record 17     tt9053874          6.0          30168
      Record 18     tt8758202          7.5          30175
      Record 19     tt0082533          6.6          30177
      Record 20     tt1741256          7.2          30195
      Record 21     tt3139086          7.5          30206
      Record 22     tt0082089          7.4          30221
      Record 23     tt0113253          4.9          30240
      Record 24     tt0056111          8.1          30246
      Record 25     tt4396630          7.4          30247
```

```
       Record 24     tt0056111          8.1          30246
       Record 25     tt4396630          7.4          30247
       Record 26     tt7668518          6.8          30248
       Record 27     tt0037382          7.8          30254
       Record 28     tt0204993          7.4          30259
       Record 29     tt0377091          7.2          30262
       Record 30     tt0417001          5.9          30275
       Record 31     tt1174730          7.4          30319
       Record 32     tt3385524          7.2          30326
       Record 33     tt0880502          7.8          30333
data block 3
       Record 34     tt0105643          2.9          30341
       Record 35     tt0439662          7.2          30354
       Record 36     tt1629757          7.2          30361
       Record 37     tt1094249          7.3          30370
       Record 38     tt0482088          7.0          30376
       Record 39     tt0408777          7.5          30391
       Record 40     tt1672723          7.4          30395
       Record 41     tt0059026          8.3          30402
       Record 42     tt4283054          8.4          30418
       Record 43     tt0485601          7.6          30423
       Record 44     tt3544082          7.1          30431
       Record 45     tt0108308          4.8          30446
       Record 46     tt8201170          5.8          30453
       Record 47     tt1500491          5.6          30456
       Record 48     tt0090887          6.1          30457
       Record 49     tt0092593          8.0          30458
```

```
      Record 48     tt0090887           6.1          30457
      Record 49     tt0092593           8.0          30458
      Record 50     tt0100994           6.5          30462
data block 4
      Record 51     tt0088526           7.9          30468
      Record 52     tt0105121           6.4          30492
      Record 53     tt0060665           7.7          30516
      Record 54     tt0899106           5.7          30522
      Record 55     tt0845046           7.0          30530
      Record 56     tt0098749           6.3          30540
      Record 57     tt0479968           4.0          30547
      Record 58     tt2294677           6.7          30548
      Record 59     tt1668191           7.4          30550
      Record 60     tt0043338           8.1          30552
      Record 61     tt1641384           8.6          30554
      Record 62     tt0083946           8.1          30569
      Record 63     tt5691670           6.5          30569
      Record 64     tt0096694           7.0          30571
      Record 65     tt0088814           6.4          30576
      Record 66     tt0116654           4.6          30578
      Record 67     tt1588398           5.3          30585
data block 5
      Record 68     tt4131606           8.7          30605
      Record 69     tt0458413           6.4          30608
      Record 70     tt3398268           7.7          30611
      Record 71     tt0192614           5.6          30619
```

```
    Record 72     tt3247714          5.6          30620
    Record 73     tt0380599          6.8          30621
    Record 74     tt1615918          4.3          30639
    Record 75     tt0053488          8.6          30658
    Record 76     tt1372686          6.1          30658
    Record 77     tt2088003          5.4          30661
    Record 78     tt0093148          6.0          30669
    Record 79     tt0110527          6.5          30672
    Record 80     tt0802999          8.9          30673
    Record 81     tt0378947          6.4          30674
    Record 82     tt0086687          7.3          30677
    Record 83     tt3735246          7.2          30693
    Record 84     tt1971352          6.4          30697
The number of data blocks accessed is 930

Average of average rating: 6.727911862221244
```

Figure 28: Output for Experiment 4 for 500MB

Experiment 5 Results

For experiment 5, our team has deleted the movies with the attribute “numVotes” equal to 1,000, updated the B+ tree accordingly, and reported the following statistics:

1. Number of times that a node is deleted during the process of updating the B+ tree
2. Number nodes of the updated B+ tree
3. Height of the updated B+ tree
4. Content of the root node and its 1st child node of the updated B+ tree

<table>
<tr><th colspan="6">B+ Tree</th></tr>
<tr><th rowspan="2">Block Size</th><th rowspan="2">Number Of Times A Node Is Deleted</th><th rowspan="2">Number Of Nodes</th><th rowspan="2">Height</th><th colspan="2">Content</th></tr>
<tr><th>Root Node</th><th>First Child of Root Node</th></tr>
<tr><td>200 B</td><td>3</td><td>131511</td><td>5</td><td colspan="2">Refer to outputs in Figure 29</td></tr>
<tr><td>500 B</td><td>1</td><td>51956</td><td>4</td><td colspan="2">Refer to outputs in Figure 30</td></tr>
</table>

```
Experiment 5:
Number of times that a node is deleted : 3
Number nodes of the updated B+ tree: 131511
Height of the updated B+ tree: 5
content of the root node:
Keys: [5, 7, 8, 10, 14, 18, 26, 41, 78, 198, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@3a71f4dd, MemoryPool.BTreeNode@7adf9f5f, MemoryPool.BTreeNode@85ede7b, MemoryPool.BTreeNode@5674cd4d, MemoryPool.BTreeNode@63961c42, 

Keys: [5, 5, 5, 5, 5, 5, 5, 5, -1, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@72ea2f77, MemoryPool.BTreeNode@33c7353a, MemoryPool.BTreeNode@681a9515, MemoryPool.BTreeNode@3af49f1c, MemoryPool.BTreeNode@19469ea2,

Please choose an option to continue:

[1] Repeat Experiments 1-5 with new block size of 500MB
[2] Exit
```

Figure 29: Output for Experiment 5 for 200MB

```
Experiment 5:
Number of times that a node is deleted : 1
Number nodes of the updated B+ tree: 51956
Height of the updated B+ tree: 4
content of the root node:
Keys: [8, 17, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1,
Pointers: [MemoryPool.BTreeNode@73a8dfcc, MemoryPool.BTreeNode@ea30797, MemoryPool.BTreeNode@7e774085, null, null, null, null, null, null, null, null, null, null, nul

Keys: [5, 5, 5, 5, 5, 5, 5, 6, 6, 6, 6, 6, 6, 6, 7, 7, 7, 7, 7, 7, 8, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1]
Pointers: [MemoryPool.BTreeNode@3f8f9dd6, MemoryPool.BTreeNode@aec6354, MemoryPool.BTreeNode@1c655221, MemoryPool.BTreeNode@58d25a40, MemoryPool.BTreeNode@1b701da1, M
```

Figure 30: Output for Experiment 5 for 500MB