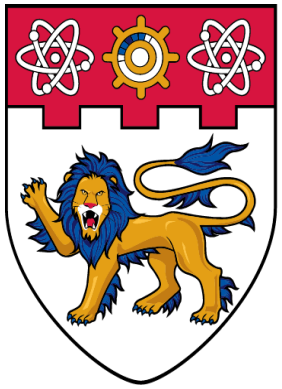

NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

CZ4031: DATABASE SYSTEM PRINCIPLES

Assignment 1

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Group 20

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INTRODUCTION

Description

In this project, we design and implement a simple storage and database system using C++ that uses B+ trees for indexing records. We support inserting, searching for and deleting records. We use a single C++ file containing all the functions.

Implementation overview

We have organised our program into the following structures and classes:

- `struct Record` containing record attributes and methods and a function `toString` for printing record values.
- `struct Disk_Block` and `struct Bucket`, containing (de)initialisation methods.
- `class BPlusTree`, which contains all the methods related to the B+ tree as explained in the B+ Tree Implementation section.
- Two functions `getTotalRecordCount` and `retrieveData` to read data from the `data.tsv` file and print the required properties.
- Functions for Experiment 3, 4 and 5 and a menu display function for users' selection.

Execution instructions

- Depending on whether the size of each block is to be 100 or 500 bytes, the easiest way of running the program is to double-click the `CZ4031_team20_proj1_100B.exe` or `CZ4031_team20_proj1_500B.exe` file, respectively, in the *Release* folder.
- Alternatively you can execute the code in your preferred IDE. We have used the Visual Studio Code IDE with the Code Runner extension installed.

Member contributions

- Leow Wei Thou, Samuel: implemented most of the storage and B+ tree functions.
- Tok Jing Xian: (fill in role)
- Chan Zhao Hui: (fill in role)
- Bhadra Soham: verified the correctness of the experiments and drafted the report.

STORAGE DESIGN AND STRUCTURE

As per the project requirements, we have defined the disk size as 10^8 bytes or 100 MB and the block size as 100 or 500 bytes depending on the question (100 bytes by default).

It is clear that each field has a fixed size of 4 bytes and hence all records have a fixed length of 12 bytes. This simplifies the packing of records into blocks and ensures that space is used as efficiently as possible with little wastage. Especially with 100-byte blocks, there is no wastage.

Some constants and predefined variables are defined as follows:

```
#define DISK_SIZE           100000000
#define BLOCK_SIZE          100
#define BLOCKS_IN_DISK      (DISK_SIZE/BLOCK_SIZE)
#define RECORD_SIZE         sizeof(Record)
#define RECORDS_PER_BLOCK   ((BLOCK_SIZE-2*sizeof(int))/RECORD_SIZE)
#define POINTER_SIZE        sizeof(uintptr_t) //4
#define DATA_FILE           "data.tsv"
const static int N =        floor((BLOCK_SIZE - POINTER_SIZE) / (POINTER_SIZE + sizeof
                               (int)));
#define RECORDS_PER_BUCKET  ((BLOCK_SIZE - (2*sizeof(int) + sizeof(bool)))/sizeof(uint
                               ptr_t) - 1)
```

Record

Attribute	Data Type	Description
`id`	`int`	tconst (only the numeric value is used)
`avg_rating`	`float`	Average rating
`num_of_votes`	`int`	Number of votes

Functions:

- `getRecordSize`: Prints the size of 1 record (= 12 bytes, with 4 bytes per field).
- `toString`: Prints the movie title identifier, average rating and number of votes.

Disk Block

Attribute	Data Type	Description
`id`	`int`	Header of the disk block
`Record`	`Object`	Record size

To get the number of records stored in a disk block, we use the following calculation:

$$\text{Number of records per block} = floor\left(\frac{\text{Block size} - \text{Size of header id}}{\text{Record size}}\right)$$

= **7** for block size 100 bytes
= **41** for block size 500 bytes.

Node

Attribute	Data Type	Description
`ptr`	`uintptr_t`	Pointer to the next node
`key`	`int`	Array of keys stored in the node
`size`	`int`	Size of the node
`isLeaf`	`bool`	Whether the node is a leaf

Functions:

- `print`: Prints the keys stored in the buckets of the node.
- `printVertical`: Prints the index keys of the root node and its first child.

Bucket

The term 'Bucket' in our project refers to an individual key-pointer pair that stores a value. A node consists of multiple buckets.

Attribute	Data Type	Description
`ptr`	`uintptr_t`	Pointer to the next bucket in the same or next node
`key`	`int`	Key stored in the bucket
`size`	`int`	Size of the bucket
`overflowed`	`bool`	Whether a bucket overflow has taken place

There are no user-defined functions for Bucket.

Dataset attributes

The dataset (`data.tsv`) used for this project contains IMDb IDs, ratings and votes for movies. The following are the attributes in the dataset:

- `tconst`: alphanumeric unique identifier of the movie title
- `averageRating`: weighted average of all the individual user ratings
- `numVotes`: number of votes the movie has received

The experiments are written in the C++ programming language to design the storage of data and the B+ tree. A sample record in `data.tsv` is as follows:

Attribute	Data type	Data example
`tconst`	String	tt0000001
`averageRating`	float	5.6
`numVotes`	int	1645

Data types used in this project are Integer/Unsigned Integer and Float, each occupying 4 bytes.

B+ TREE DESIGN AND IMPLEMENTATION

Attributes

Our `BPlusTree` class is designed with the following attributes. The height of the tree and the number of nodes and buckets are all initialised as 0.

```
Node* root;
int min_key_in_leaf = floor((N + 1) / 2);
// floor(N / 2)
int min_key_in_nonleaf = floor(N / 2);
// height of tree (inclusive of leaf level)
int height = 0;
// number of nodes in the tree
int num_of_nodes = 0;
// number of buckets in the tree
int num_of_buckets = 0;
```

- Maximum number of keys in internal or leaf node = N
- Minimum number of keys in internal node = $floor\ (\frac{N}{2})$
- Minimum number of keys in leaf node = $floor\ (\frac{N+1}{2})$

Functions

The `BPlusTree` class has the following functions:

- `insertIntoBucket`
- `insertIntoLeaf`
- `searchForLeafNodeWithKey`
- `searchAndPrintLeafNode`
- `searchForLeftLeafSiblingOfKey`
- `searchAndPrintExperimentFour`
- `insertChildNode`
- `splitFullLeafNodeForInsert`
- `insertIntoFullNonleafNode`
- `insertParentUpdate`
- `addRecord`
- `getBucket`
- `changeKeyParentUpdate`
- `getKeyPositionInNode`
- `getNodePositionInParent`
- `getLeafSiblings`
- `deleteParentUpdate`
- `deleteFullBucket`
- `deleteRecord`
- `getParentNode`
- `getLeafParent`
- `displayTree`

They are briefly described as follows:

- **insertIntoBucket**: Inserts a record into an existing bucket with its position in the leaf node. Also checks if a bucket is full and, if so, creates a new overflow bucket for insertion.
- **insertIntoLeaf**: inserts a record into a leaf node that has space and returns its input position. If the record is bigger than the current last key, it creates a new bucket to store the record.
- **searchForLeafNodeWithKey**: Searches through node recursively to get the leaf node of the record. Returns the parent node.
- **searchAndPrintLeafNode**: Searches for the leaf node with the given key and prints out the first 5 nodes accessed. Returns the total number of nodes accessed.

- **searchForLeftLeafSiblingOfKey**: Searches through node recursively to get left leaf sibling of record. Returns the parent node.
- **searchAndPrintExperimentFour**: This function has been designed for Experiment 4, which involves a range search query. If the key passed as the argument of the function is contained in the B+ tree nodes, the corresponding nodes are printed out.
- **insertChildNode**: Inserts a child node into a parent node.
- **splitFullLeafNodeForInsert**: Splits the full leaf node into two and creates a slot for insertion. Returns the node to insert into, and the input position. This takes into account all the possibilities for which keys are to be shifted to another node, and to where.
- **insertIntoFullNonleafNode**: Splits the full nonleaf node into two and inserts the node passed into the function.
- **insertParentUpdate**: Updates all the parent nodes recursively on insertion of a child.
- **addRecord**: Adds a record into the B+ tree. The function has been configured to use `num_of_votes` as a key. If the tree does not exist, it creates a root node. If the current leaf node has no parent, it creates a parent and sets it as the root.
- **getBucket**: Given a key, returns the corresponding bucket in which it is stored.
- **changeKeyParentUpdate**: Updates all the parent nodes recursively when a key is changed.
- **getKeyPositionInNode**: Returns the position of a key in a node (-1 if not found).
- **getNodePositionInParent**: Returns the position of a key in the parent (-1 if not found).
- **getLeafSiblings**: Returns the sibling nodes of a child node.
- **deleteParentUpdate**: Updates parent nodes recursively if the parent node lacks the minimum required size.
- **deleteFullBucket**: Deletes a bucket within a node.
- **deleteRecord**: Deletes all records with given key. Returns true if the bucket of records is found and successfully deleted.
- **getParentNode**: Returns the parent node, given the tree and child node.
- **getLeafParent**: Returns the parent of a leaf node.
- **displayTree**: Prints the tree.

EXPERIMENTS

Part 1: With block size = 100 bytes

General statistics:

- Blocks in disk = 1000000 (1 million, 10^6)
- No. of records per block = 7
- Total number of records = 1070318

Experiment 1

Number of blocks used: 152903
Size of database: 12.7592MB

Experiment 2

Size of each pointer: 4B
Number of maximum keys in a B+ tree node (n): 12
Number of maximum records in a B+ tree bucket: 21
Number of nodes in the B+ tree: 2380
Number of buckets in the B+ tree: 66307
Height of the B+ tree: 5

Root node:
Index Keys 1: 7042
Index Keys 2: 24228

Root node's first child:
Index Keys 1: 659
Index Keys 2: 1645
Index Keys 3: 2407
Index Keys 4: 3250
Index Keys 5: 3938
Index Keys 6: 4704
Index Keys 7: 5198
Index Keys 8: 5787

Experiment 3

Nodes Accessed:

Node 1
Index Keys 1: 7042
Index Keys 2: 24228

Node 2
Index Keys 1: 659
Index Keys 2: 1645
Index Keys 3: 2407
Index Keys 4: 3250
Index Keys 5: 3938
Index Keys 6: 4704
Index Keys 7: 5198
Index Keys 8: 5787

Node 3
Index Keys 1: 74
Index Keys 2: 187
Index Keys 3: 262
Index Keys 4: 342
Index Keys 5: 411
Index Keys 6: 475
Index Keys 7: 574

Node 4
Index Keys 1: 483
Index Keys 2: 491
Index Keys 3: 503
Index Keys 4: 509
Index Keys 5: 517
Index Keys 6: 528
Index Keys 7: 534
Index Keys 8: 544
Index Keys 9: 553
Index Keys 10: 561
Index Keys 11: 567

Node 5
Index Keys 1: 491
Index Keys 2: 492
Index Keys 3: 493
Index Keys 4: 494
Index Keys 5: 495
Index Keys 6: 496
Index Keys 7: 497
Index Keys 8: 498
Index Keys 9: 499
Index Keys 10: 500
Index Keys 11: 501
Index Keys 12: 502

Total Nodes Accessed: 5

Data Block 514
Record 1 tconst value: 13658
Record 2 tconst value: 13662
Record 3 tconst value: 13668
Record 4 tconst value: 13672
Record 5 tconst value: 13674
Record 6 tconst value: 13679
Record 7 tconst value: 13681

Total Data Blocks accessed: 110

Data Block 1289
Record 1 tconst value: 24559
Record 2 tconst value: 24560
Record 3 tconst value: 24561
Record 4 tconst value: 24562
Record 5 tconst value: 24563
Record 6 tconst value: 24564
Record 7 tconst value: 24567

Data Block 1690
Record 1 tconst value: 28274
Record 2 tconst value: 28275
Record 3 tconst value: 28276
Record 4 tconst value: 28277
Record 5 tconst value: 28278
Record 6 tconst value: 28279
Record 7 tconst value: 28280

Data Block 3255
Record 1 tconst value: 41955
Record 2 tconst value: 41956
Record 3 tconst value: 41957
Record 4 tconst value: 41958
Record 5 tconst value: 41959
Record 6 tconst value: 41961
Record 7 tconst value: 41962

Data Block 3884
Record 1 tconst value: 47356
Record 2 tconst value: 47357
Record 3 tconst value: 47358
Record 4 tconst value: 47359
Record 5 tconst value: 47360
Record 6 tconst value: 47361
Record 7 tconst value: 47362

Average Rating = 6.73182

Experiment 4

Accessing records with numVotes ranging from 30000 to 40000

Nodes Accessed:
Node 1
Index Keys 1: 7042
Index Keys 2: 24228

Node 2
Index Keys 1: 32062
Index Keys 2: 42764
Index Keys 3: 58886
Index Keys 4: 86813
Index Keys 5: 111495
Index Keys 6: 168792
Index Keys 7: 299582

Node 3
Index Keys 1: 24729
Index Keys 2: 25374
Index Keys 3: 25873
Index Keys 4: 26498
Index Keys 5: 27105
Index Keys 6: 27542
Index Keys 7: 28200
Index Keys 8: 28769
Index Keys 9: 29399
Index Keys 10: 30034
Index Keys 11: 31006
Index Keys 12: 31523

Node 4
Index Keys 1: 29587
Index Keys 2: 29633
Index Keys 3: 29730
Index Keys 4: 29774
Index Keys 5: 29823
Index Keys 6: 29880
Index Keys 7: 29959

Node 5
Index Keys 1: 29959
Index Keys 2: 29962
Index Keys 3: 29974
Index Keys 4: 29975
Index Keys 5: 29978
Index Keys 6: 29982
Index Keys 7: 29988
Index Keys 8: 29996
Index Keys 9: 30022

Total Nodes Accessed: 112

Data Block 585
Record 1 tconst value: 15318
Record 2 tconst value: 15322
Record 3 tconst value: 15324
Record 4 tconst value: 15329
Record 5 tconst value: 15331
Record 6 tconst value: 15339
Record 7 tconst value: 15342

Data Block 1522
Record 1 tconst value: 26773
Record 2 tconst value: 26774
Record 3 tconst value: 26775
Record 4 tconst value: 26776
Record 5 tconst value: 26777
Record 6 tconst value: 26778
Record 7 tconst value: 26779

Data Block 1763
Record 1 tconst value: 28943
Record 2 tconst value: 28944
Record 3 tconst value: 28945
Record 4 tconst value: 28946
Record 5 tconst value: 28947
Record 6 tconst value: 28949
Record 7 tconst value: 28950

Data Block 2365
Record 1 tconst value: 34242
Record 2 tconst value: 34243
Record 3 tconst value: 34244
Record 4 tconst value: 34245
Record 5 tconst value: 34246
Record 6 tconst value: 34247
Record 7 tconst value: 34248

Data Block 2734
Record 1 tconst value: 37376
Record 2 tconst value: 37377
Record 3 tconst value: 37378
Record 4 tconst value: 37379
Record 5 tconst value: 37380
Record 6 tconst value: 37382
Record 7 tconst value: 37383

Total Data Blocks accessed: 953

Average Rating = 6.72791

Experiment 5

Number of nodes deleted: 0
Number of buckets deleted: 2
Number of nodes in the B+ tree: 2380
Number of buckets in the B+ tree: 66305
Height of the B+ tree: 5

Root node:
Index Keys 1: 7042
Index Keys 2: 24228

Root node's first child:
Index Keys 1: 659
Index Keys 2: 1645
Index Keys 3: 2407
Index Keys 4: 3250
Index Keys 5: 3938
Index Keys 6: 4704
Index Keys 7: 5198
Index Keys 8: 5787

Screenshots of partial output:

```
Disk capacity:  100000000B
Block size:     100B
Blocks in disk: 1000000
Record size:    12B
Num of records in a block:      7
Total num of records:   1070318

        - Experiment 1 -

Num of blocks utilized: 152903
Size of database:       14.582MB

        - Experiment 2 -

Size of each pointer: 4B
Number of maximum keys in a B+ tree node (n): 12
Number of maximum records in a B+ tree bucket: 21
Number of nodes in the B+ tree: 2380
Number of buckets in the B+ tree: 66307
Height of the B+ tree: 5

Root node:
Index Keys 1: 7042
Index Keys 2: 24228

Root node's first child:
Index Keys 1: 659
Index Keys 2: 1645
Index Keys 3: 2407
Index Keys 4: 3250
Index Keys 5: 3938
Index Keys 6: 4704
Index Keys 7: 5198
Index Keys 8: 5787


        - Menu -

1 - Experiment 3
2 - Experiment 4
3 - Experiment 5
4 - Exit program

Enter an option (1/2/3/4): 1
```

```
        - Experiment 4 -

Accessing records with numVotes ranging from 30000 to 40000
Nodes Accessed:
Node 1
Index Keys 1: 7042
Index Keys 2: 24228

Node 2
Index Keys 1: 32062
Index Keys 2: 42764
Index Keys 3: 58886
Index Keys 4: 86813
Index Keys 5: 111495
Index Keys 6: 168792
Index Keys 7: 299582

Node 3
Index Keys 1: 24729
Index Keys 2: 25374
Index Keys 3: 25873
Index Keys 4: 26498
Index Keys 5: 27105
Index Keys 6: 27542
Index Keys 7: 28200
Index Keys 8: 28769
Index Keys 9: 29399
Index Keys 10: 30034
Index Keys 11: 31006
Index Keys 12: 31523

Node 4
Index Keys 1: 29587
Index Keys 2: 29633
Index Keys 3: 29730
Index Keys 4: 29774
Index Keys 5: 29823
Index Keys 6: 29880
Index Keys 7: 29959

Node 5
Index Keys 1: 29959
Index Keys 2: 29962
Index Keys 3: 29974
Index Keys 4: 29975
Index Keys 5: 29978
Index Keys 6: 29982
Index Keys 7: 29988
Index Keys 8: 29996
Index Keys 9: 30022

Total Nodes Accessed: 112
```

```
        - Menu -

1 - Experiment 3
2 - Experiment 4
3 - Experiment 5
4 - Exit program

Enter an option (1/2/3/4): 3


        Experiment 5:

Deleting records with numVotes of 1000
Records deleted successfully!
Number of nodes deleted: 0
Number of buckets deleted: 2
Number of nodes in the B+ tree: 2380
Number of buckets in the B+ tree: 66305
Height of the B+ tree: 5

Root node:
Index Keys 1: 7042
Index Keys 2: 24228

Root node's first child:
Index Keys 1: 659
Index Keys 2: 1645
Index Keys 3: 2407
Index Keys 4: 3250
Index Keys 5: 3938
Index Keys 6: 4704
Index Keys 7: 5198
Index Keys 8: 5787
```

Part 2: With block size = 500 bytes

General statistics:

- Blocks in disk = 200,000
- No. of records per block = 41
- Total number of records: 1070318

Experiment 1

Number of blocks used: 26106
Size of database: 12.4483MB

Experiment 2

Size of each pointer: 4B
Number of maximum keys in a B+ tree node (n): 62
Number of maximum records in a B+ tree bucket: 121
Number of nodes in the B+ tree: 425
Number of buckets in the B+ tree: 25940
Height of the B+ tree: 3

Root node:
Index Keys 1: 1565
Index Keys 2: 4375
Index Keys 3: 6543
Index Keys 4: 10547
Index Keys 5: 15855
Index Keys 6: 27189
Index Keys 7: 69737
Index Keys 8: 139647

Root node's first child:
Index Keys 1: 59
Index Keys 2: 91
Index Keys 3: 128
Index Keys 4: 184
Index Keys 5: 219
Index Keys 6: 262
Index Keys 7: 298
Index Keys 8: 334
Index Keys 9: 389
Index Keys 10: 445
Index Keys 11: 478
Index Keys 12: 517
Index Keys 13: 550
Index Keys 14: 583
Index Keys 15: 639
Index Keys 16: 677
Index Keys 17: 717
Index Keys 18: 768
Index Keys 19: 799
Index Keys 20: 831
Index Keys 21: 863
Index Keys 22: 895
Index Keys 23: 949
Index Keys 24: 984
Index Keys 25: 1017
Index Keys 26: 1063
Index Keys 27: 1117
Index Keys 28: 1164
Index Keys 29: 1214
Index Keys 30: 1275
Index Keys 31: 1337
Index Keys 32: 1391
Index Keys 33: 1446
Index Keys 34: 1507

Experiment 3

Nodes Accessed:
Node 1
Index Keys 1: 1565
Index Keys 2: 4375
Index Keys 3: 6543
Index Keys 4: 10547
Index Keys 5: 15855
Index Keys 6: 27189
Index Keys 7: 69737
Index Keys 8: 139647

Node 2
Index Keys 1: 59
Index Keys 2: 91
Index Keys 3: 128
Index Keys 4: 184
Index Keys 5: 219
Index Keys 6: 262
Index Keys 7: 298
Index Keys 8: 334
Index Keys 9: 389
Index Keys 10: 445
Index Keys 11: 478
Index Keys 12: 517
Index Keys 13: 550
Index Keys 14: 583
Index Keys 15: 639
Index Keys 16: 677
Index Keys 17: 717
Index Keys 18: 768
Index Keys 19: 799
Index Keys 20: 831
Index Keys 21: 863
Index Keys 22: 895
Index Keys 23: 949
Index Keys 24: 984
Index Keys 25: 1017
Index Keys 26: 1063
Index Keys 27: 1117
Index Keys 28: 1164
Index Keys 29: 1214
Index Keys 30: 1275
Index Keys 31: 1337
Index Keys 32: 1391
Index Keys 33: 1446
Index Keys 34: 1507

Node 3
Index Keys 1: 478
Index Keys 2: 479
Index Keys 3: 480
Index Keys 4: 481
Index Keys 5: 482
Index Keys 6: 483
Index Keys 7: 484
Index Keys 8: 485
Index Keys 9: 486
Index Keys 10: 487
Index Keys 11: 488
Index Keys 12: 489
Index Keys 13: 490
Index Keys 14: 491
Index Keys 15: 492
Index Keys 16: 493
Index Keys 17: 494
Index Keys 18: 495
Index Keys 19: 496
Index Keys 20: 497
Index Keys 21: 498
Index Keys 22: 499
Index Keys 23: 500
Index Keys 24: 501
Index Keys 25: 502
Index Keys 26: 503
Index Keys 27: 504
Index Keys 28: 505
Index Keys 29: 506
Index Keys 30: 507
Index Keys 31: 508
Index Keys 32: 509
Index Keys 33: 510
Index Keys 34: 511
Index Keys 35: 512
Index Keys 36: 513
Index Keys 37: 514
Index Keys 38: 515
Index Keys 39: 516

Total Nodes Accessed: 3

Data Block 88
Record 1 tconst value: 13555
Record 2 tconst value: 13556
Record 3 tconst value: 13570
Record 4 tconst value: 13571

Record 5 tconst value: 13572
Record 6 tconst value: 13573
Record 7 tconst value: 13574
Record 8 tconst value: 13579
Record 9 tconst value: 13590
Record 10 tconst value: 13592
Record 11 tconst value: 13596
Record 12 tconst value: 13597
Record 13 tconst value: 13603
Record 14 tconst value: 13607
Record 15 tconst value: 13611
Record 16 tconst value: 13615
Record 17 tconst value: 13617
Record 18 tconst value: 13619
Record 19 tconst value: 13620
Record 20 tconst value: 13624
Record 21 tconst value: 13626
Record 22 tconst value: 13627
Record 23 tconst value: 13629
Record 24 tconst value: 13631
Record 25 tconst value: 13658
Record 26 tconst value: 13662
Record 27 tconst value: 13668
Record 28 tconst value: 13672
Record 29 tconst value: 13674
Record 30 tconst value: 13679
Record 31 tconst value: 13681
Record 32 tconst value: 13682
Record 33 tconst value: 13687
Record 34 tconst value: 13688
Record 35 tconst value: 13690
Record 36 tconst value: 13704
Record 37 tconst value: 13705
Record 38 tconst value: 13710
Record 39 tconst value: 13716
Record 40 tconst value: 13719
Record 41 tconst value: 13724

Data Block 220
Record 1 tconst value: 24501
Record 2 tconst value: 24503
Record 3 tconst value: 24505
Record 4 tconst value: 24506
Record 5 tconst value: 24507
Record 6 tconst value: 24509
Record 7 tconst value: 24510
Record 8 tconst value: 24511
Record 9 tconst value: 24513
Record 10 tconst value: 24514
Record 11 tconst value: 24516
Record 12 tconst value: 24517
Record 13 tconst value: 24518
Record 14 tconst value: 24519
Record 15 tconst value: 24523
Record 16 tconst value: 24524
Record 17 tconst value: 24527
Record 18 tconst value: 24531
Record 19 tconst value: 24532
Record 20 tconst value: 24534
Record 21 tconst value: 24535
Record 22 tconst value: 24536
Record 23 tconst value: 24537
Record 24 tconst value: 24538
Record 25 tconst value: 24539
Record 26 tconst value: 24542
Record 27 tconst value: 24545
Record 28 tconst value: 24546
Record 29 tconst value: 24547
Record 30 tconst value: 24548
Record 31 tconst value: 24549
Record 32 tconst value: 24550
Record 33 tconst value: 24551
Record 34 tconst value: 24553
Record 35 tconst value: 24554
Record 36 tconst value: 24555
Record 37 tconst value: 24558
Record 38 tconst value: 24559
Record 39 tconst value: 24560
Record 40 tconst value: 24561
Record 41 tconst value: 24562

Data Block 289
Record 1 tconst value: 28254
Record 2 tconst value: 28255
Record 3 tconst value: 28256
Record 4 tconst value: 28257
Record 5 tconst value: 28258
Record 6 tconst value: 28259
Record 7 tconst value: 28260
Record 8 tconst value: 28264
Record 9 tconst value: 28267
Record 10 tconst value: 28268
Record 11 tconst value: 28269
Record 12 tconst value: 28270
Record 13 tconst value: 28271
Record 14 tconst value: 28272
Record 15 tconst value: 28273
Record 16 tconst value: 28274
Record 17 tconst value: 28275
Record 18 tconst value: 28276

Record 19 tconst value: 28277
Record 20 tconst value: 28278
Record 21 tconst value: 28279
Record 22 tconst value: 28280
Record 23 tconst value: 28281
Record 24 tconst value: 28282
Record 25 tconst value: 28283
Record 26 tconst value: 28284
Record 27 tconst value: 28285
Record 28 tconst value: 28286
Record 29 tconst value: 28287
Record 30 tconst value: 28288
Record 31 tconst value: 28289
Record 32 tconst value: 28290
Record 33 tconst value: 28291
Record 34 tconst value: 28292
Record 35 tconst value: 28294
Record 36 tconst value: 28296
Record 37 tconst value: 28297
Record 38 tconst value: 28298
Record 39 tconst value: 28299
Record 40 tconst value: 28300
Record 41 tconst value: 28301

Data Block 556
Record 1 tconst value: 41926
Record 2 tconst value: 41928
Record 3 tconst value: 41929
Record 4 tconst value: 41930
Record 5 tconst value: 41931
Record 6 tconst value: 41932
Record 7 tconst value: 41933
Record 8 tconst value: 41934
Record 9 tconst value: 41935
Record 10 tconst value: 41938
Record 11 tconst value: 41939
Record 12 tconst value: 41940
Record 13 tconst value: 41943
Record 14 tconst value: 41944
Record 15 tconst value: 41945
Record 16 tconst value: 41946
Record 17 tconst value: 41947
Record 18 tconst value: 41948
Record 19 tconst value: 41949
Record 20 tconst value: 41951
Record 21 tconst value: 41952
Record 22 tconst value: 41953
Record 23 tconst value: 41954
Record 24 tconst value: 41955
Record 25 tconst value: 41956
Record 26 tconst value: 41957
Record 27 tconst value: 41958
Record 28 tconst value: 41959
Record 29 tconst value: 41961
Record 30 tconst value: 41962
Record 31 tconst value: 41963
Record 32 tconst value: 41966
Record 33 tconst value: 41967
Record 34 tconst value: 41968
Record 35 tconst value: 41969
Record 36 tconst value: 41971
Record 37 tconst value: 41974
Record 38 tconst value: 41975
Record 39 tconst value: 41976
Record 40 tconst value: 41977
Record 41 tconst value: 41978

Data Block 664
Record 1 tconst value: 47358
Record 2 tconst value: 47359
Record 3 tconst value: 47360
Record 4 tconst value: 47361
Record 5 tconst value: 47362
Record 6 tconst value: 47363
Record 7 tconst value: 47364
Record 8 tconst value: 47365
Record 9 tconst value: 47366
Record 10 tconst value: 47367
Record 11 tconst value: 47368
Record 12 tconst value: 47369
Record 13 tconst value: 47370
Record 14 tconst value: 47371
Record 15 tconst value: 47372
Record 16 tconst value: 47373
Record 17 tconst value: 47374
Record 18 tconst value: 47375
Record 19 tconst value: 47376
Record 20 tconst value: 47377
Record 21 tconst value: 47378
Record 22 tconst value: 47379
Record 23 tconst value: 47380
Record 24 tconst value: 47381
Record 25 tconst value: 47382
Record 26 tconst value: 47383
Record 27 tconst value: 47385
Record 28 tconst value: 47386
Record 29 tconst value: 47387
Record 30 tconst value: 47388
Record 31 tconst value: 47389
Record 32 tconst value: 47390

Record 33 tconst value: 47391
Record 34 tconst value: 47392
Record 35 tconst value: 47393
Record 36 tconst value: 47395
Record 37 tconst value: 47396
Record 38 tconst value: 47397
Record 39 tconst value: 47398
Record 40 tconst value: 47400
Record 41 tconst value: 47401

Total Data Blocks accessed: 110
Average Rating = 6.73182

Experiment 4

Accessing records with numVotes ranging from 30000 to 40000

Nodes Accessed:
Node 1
Index Keys 1: 1565
Index Keys 2: 4375
Index Keys 3: 6543
Index Keys 4: 10547
Index Keys 5: 15855
Index Keys 6: 27189
Index Keys 7: 69737
Index Keys 8: 139647

Node 2
Index Keys 1: 27562
Index Keys 2: 28117
Index Keys 3: 28609
Index Keys 4: 29136
Index Keys 5: 29514
Index Keys 6: 29818
Index Keys 7: 30254
Index Keys 8: 30571
Index Keys 9: 30816
Index Keys 10: 31173
Index Keys 11: 31674
Index Keys 12: 32227
Index Keys 13: 32878
Index Keys 14: 33248
Index Keys 15: 33594
Index Keys 16: 34423
Index Keys 17: 34869
Index Keys 18: 35400
Index Keys 19: 35971
Index Keys 20: 36589
Index Keys 21: 37252
Index Keys 22: 37992
Index Keys 23: 38490
Index Keys 24: 39169
Index Keys 25: 39979
Index Keys 26: 40677
Index Keys 27: 41262
Index Keys 28: 41740
Index Keys 29: 42408
Index Keys 30: 42842
Index Keys 31: 43296
Index Keys 32: 44203
Index Keys 33: 45136
Index Keys 34: 46391
Index Keys 35: 46855
Index Keys 36: 47414
Index Keys 37: 47936
Index Keys 38: 48554
Index Keys 39: 49599
Index Keys 40: 50498
Index Keys 41: 51065
Index Keys 42: 51788
Index Keys 43: 52497
Index Keys 44: 53186
Index Keys 45: 53992
Index Keys 46: 54807
Index Keys 47: 56042
Index Keys 48: 57049
Index Keys 49: 58594
Index Keys 50: 60347
Index Keys 51: 61329
Index Keys 52: 62221
Index Keys 53: 62942
Index Keys 54: 63924
Index Keys 55: 65573
Index Keys 56: 66415
Index Keys 57: 67267
Index Keys 58: 68321

Node 3
Index Keys 1: 29818
Index Keys 2: 29819
Index Keys 3: 29823
Index Keys 4: 29824

Index Keys 5: 29828
Index Keys 6: 29834
Index Keys 7: 29848
Index Keys 8: 29861
Index Keys 9: 29869
Index Keys 10: 29876
Index Keys 11: 29880
Index Keys 12: 29882
Index Keys 13: 29900
Index Keys 14: 29910
Index Keys 15: 29919
Index Keys 16: 29949
Index Keys 17: 29954
Index Keys 18: 29956
Index Keys 19: 29959
Index Keys 20: 29962
Index Keys 21: 29974
Index Keys 22: 29975
Index Keys 23: 29978
Index Keys 24: 29982
Index Keys 25: 29988
Index Keys 26: 29996
Index Keys 27: 30022
Index Keys 28: 30034
Index Keys 29: 30037
Index Keys 30: 30041
Index Keys 31: 30049
Index Keys 32: 30053
Index Keys 33: 30056
Index Keys 34: 30078
Index Keys 35: 30081
Index Keys 36: 30085
Index Keys 37: 30090
Index Keys 38: 30136
Index Keys 39: 30144
Index Keys 40: 30149
Index Keys 41: 30158
Index Keys 42: 30168
Index Keys 43: 30175
Index Keys 44: 30177
Index Keys 45: 30195
Index Keys 46: 30206
Index Keys 47: 30221
Index Keys 48: 30240
Index Keys 49: 30246
Index Keys 50: 30247
Index Keys 51: 30248

Node 4
Index Keys 1: 30254
Index Keys 2: 30259
Index Keys 3: 30262
Index Keys 4: 30275
Index Keys 5: 30319
Index Keys 6: 30326
Index Keys 7: 30333
Index Keys 8: 30341
Index Keys 9: 30354
Index Keys 10: 30361
Index Keys 11: 30370
Index Keys 12: 30376
Index Keys 13: 30391
Index Keys 14: 30395
Index Keys 15: 30402
Index Keys 16: 30418
Index Keys 17: 30423
Index Keys 18: 30431
Index Keys 19: 30446
Index Keys 20: 30453
Index Keys 21: 30456
Index Keys 22: 30457
Index Keys 23: 30458
Index Keys 24: 30462
Index Keys 25: 30468
Index Keys 26: 30492
Index Keys 27: 30516
Index Keys 28: 30522
Index Keys 29: 30530
Index Keys 30: 30540
Index Keys 31: 30547
Index Keys 32: 30548
Index Keys 33: 30550
Index Keys 34: 30552
Index Keys 35: 30554
Index Keys 36: 30569

Node 5
Index Keys 1: 30571
Index Keys 2: 30576
Index Keys 3: 30578
Index Keys 4: 30585
Index Keys 5: 30605
Index Keys 6: 30608
Index Keys 7: 30611
Index Keys 8: 30619
Index Keys 9: 30620
Index Keys 10: 30621
Index Keys 11: 30639
Index Keys 12: 30658
Index Keys 13: 30661
Index Keys 14: 30669
Index Keys 15: 30672

Index Keys 16: 30673
Index Keys 17: 30674
Index Keys 18: 30677
Index Keys 19: 30693
Index Keys 20: 30697
Index Keys 21: 30699
Index Keys 22: 30705
Index Keys 23: 30714
Index Keys 24: 30715
Index Keys 25: 30726
Index Keys 26: 30737
Index Keys 27: 30755
Index Keys 28: 30766
Index Keys 29: 30769
Index Keys 30: 30770
Index Keys 31: 30775
Index Keys 32: 30778
Index Keys 33: 30788
Index Keys 34: 30797
Index Keys 35: 30800

Total Nodes Accessed: 22

Data Block 100
Record 1 tconst value: 15214
Record 2 tconst value: 15217
Record 3 tconst value: 15219
Record 4 tconst value: 15222
Record 5 tconst value: 15224
Record 6 tconst value: 15228
Record 7 tconst value: 15229
Record 8 tconst value: 15232
Record 9 tconst value: 15233
Record 10 tconst value: 15239
Record 11 tconst value: 15241
Record 12 tconst value: 15243
Record 13 tconst value: 15245
Record 14 tconst value: 15253
Record 15 tconst value: 15256
Record 16 tconst value: 15258
Record 17 tconst value: 15263
Record 18 tconst value: 15268
Record 19 tconst value: 15270
Record 20 tconst value: 15273
Record 21 tconst value: 15284
Record 22 tconst value: 15285
Record 23 tconst value: 15287
Record 24 tconst value: 15289
Record 25 tconst value: 15299
Record 26 tconst value: 15310
Record 27 tconst value: 15311
Record 28 tconst value: 15312
Record 29 tconst value: 15313
Record 30 tconst value: 15318
Record 31 tconst value: 15322
Record 32 tconst value: 15324
Record 33 tconst value: 15329
Record 34 tconst value: 15331
Record 35 tconst value: 15339
Record 36 tconst value: 15342
Record 37 tconst value: 15343
Record 38 tconst value: 15347
Record 39 tconst value: 15349
Record 40 tconst value: 15353
Record 41 tconst value: 15355

Data Block 260
Record 1 tconst value: 26738
Record 2 tconst value: 26739
Record 3 tconst value: 26740
Record 4 tconst value: 26741
Record 5 tconst value: 26742
Record 6 tconst value: 26743
Record 7 tconst value: 26744
Record 8 tconst value: 26746
Record 9 tconst value: 26747
Record 10 tconst value: 26748
Record 11 tconst value: 26749
Record 12 tconst value: 26751
Record 13 tconst value: 26752
Record 14 tconst value: 26753
Record 15 tconst value: 26754
Record 16 tconst value: 26755
Record 17 tconst value: 26756
Record 18 tconst value: 26757
Record 19 tconst value: 26758
Record 20 tconst value: 26759
Record 21 tconst value: 26760
Record 22 tconst value: 26761
Record 23 tconst value: 26762
Record 24 tconst value: 26766
Record 25 tconst value: 26768
Record 26 tconst value: 26769
Record 27 tconst value: 26771
Record 28 tconst value: 26772
Record 29 tconst value: 26773
Record 30 tconst value: 26774
Record 31 tconst value: 26775
Record 32 tconst value: 26776
Record 33 tconst value: 26777
Record 34 tconst value: 26778
Record 35 tconst value: 26779

Record 36 tconst value: 26781
Record 37 tconst value: 26783
Record 38 tconst value: 26784
Record 39 tconst value: 26785
Record 40 tconst value: 26786
Record 41 tconst value: 26787

Data Block 301
Record 1 tconst value: 28902
Record 2 tconst value: 28904
Record 3 tconst value: 28905
Record 4 tconst value: 28906
Record 5 tconst value: 28907
Record 6 tconst value: 28908
Record 7 tconst value: 28909
Record 8 tconst value: 28910
Record 9 tconst value: 28912
Record 10 tconst value: 28913
Record 11 tconst value: 28914
Record 12 tconst value: 28915
Record 13 tconst value: 28916
Record 14 tconst value: 28918
Record 15 tconst value: 28919
Record 16 tconst value: 28920
Record 17 tconst value: 28921
Record 18 tconst value: 28923
Record 19 tconst value: 28925
Record 20 tconst value: 28927
Record 21 tconst value: 28929
Record 22 tconst value: 28930
Record 23 tconst value: 28931
Record 24 tconst value: 28932
Record 25 tconst value: 28933
Record 26 tconst value: 28934
Record 27 tconst value: 28935
Record 28 tconst value: 28936
Record 29 tconst value: 28937
Record 30 tconst value: 28938
Record 31 tconst value: 28939
Record 32 tconst value: 28940
Record 33 tconst value: 28941
Record 34 tconst value: 28942
Record 35 tconst value: 28943
Record 36 tconst value: 28944
Record 37 tconst value: 28945
Record 38 tconst value: 28946
Record 39 tconst value: 28947
Record 40 tconst value: 28949
Record 41 tconst value: 28950

Data Block 404
Record 1 tconst value: 34209
Record 2 tconst value: 34210
Record 3 tconst value: 34213
Record 4 tconst value: 34214
Record 5 tconst value: 34216
Record 6 tconst value: 34217
Record 7 tconst value: 34220
Record 8 tconst value: 34221
Record 9 tconst value: 34222
Record 10 tconst value: 34223
Record 11 tconst value: 34224
Record 12 tconst value: 34225
Record 13 tconst value: 34226
Record 14 tconst value: 34227
Record 15 tconst value: 34229
Record 16 tconst value: 34231
Record 17 tconst value: 34232
Record 18 tconst value: 34233
Record 19 tconst value: 34234
Record 20 tconst value: 34235
Record 21 tconst value: 34236
Record 22 tconst value: 34237
Record 23 tconst value: 34239
Record 24 tconst value: 34240
Record 25 tconst value: 34241
Record 26 tconst value: 34242
Record 27 tconst value: 34243
Record 28 tconst value: 34244
Record 29 tconst value: 34245
Record 30 tconst value: 34246
Record 31 tconst value: 34247
Record 32 tconst value: 34248
Record 33 tconst value: 34249
Record 34 tconst value: 34251
Record 35 tconst value: 34252
Record 36 tconst value: 34253
Record 37 tconst value: 34254
Record 38 tconst value: 34255
Record 39 tconst value: 34256
Record 40 tconst value: 34258
Record 41 tconst value: 34259

Data Block 467
Record 1 tconst value: 37347
Record 2 tconst value: 37348
Record 3 tconst value: 37349
Record 4 tconst value: 37352
Record 5 tconst value: 37353
Record 6 tconst value: 37354
Record 7 tconst value: 37355
Record 8 tconst value: 37356

Record 9 tconst value: 37359
Record 10 tconst value: 37360
Record 11 tconst value: 37361
Record 12 tconst value: 37362
Record 13 tconst value: 37363
Record 14 tconst value: 37364
Record 15 tconst value: 37365
Record 16 tconst value: 37366
Record 17 tconst value: 37367
Record 18 tconst value: 37368
Record 19 tconst value: 37369
Record 20 tconst value: 37370
Record 21 tconst value: 37371
Record 22 tconst value: 37372
Record 23 tconst value: 37373
Record 24 tconst value: 37374
Record 25 tconst value: 37375
Record 26 tconst value: 37376
Record 27 tconst value: 37377
Record 28 tconst value: 37378
Record 29 tconst value: 37379
Record 30 tconst value: 37380
Record 31 tconst value: 37382
Record 32 tconst value: 37383
Record 33 tconst value: 37384
Record 34 tconst value: 37385
Record 35 tconst value: 37386
Record 36 tconst value: 37387
Record 37 tconst value: 37388
Record 38 tconst value: 37389
Record 39 tconst value: 37390
Record 40 tconst value: 37391
Record 41 tconst value: 37393

Total Data Blocks accessed: 953
Average Rating = 6.72791

Experiment 5

Number of nodes deleted: 0
Number of buckets deleted: 1
Number of nodes in the B+ tree: 425
Number of buckets in the B+ tree: 25939
Height of the B+ tree: 3

Root node:
Index Keys 1: 1565
Index Keys 2: 4375
Index Keys 3: 6543
Index Keys 4: 10547
Index Keys 5: 15855
Index Keys 6: 27189
Index Keys 7: 69737
Index Keys 8: 139647
Root node's first child:
Index Keys 1: 59
Index Keys 2: 91
Index Keys 3: 128
Index Keys 4: 184
Index Keys 5: 219
Index Keys 6: 262
Index Keys 7: 298
Index Keys 8: 334
Index Keys 9: 389
Index Keys 10: 445
Index Keys 11: 478
Index Keys 12: 517
Index Keys 13: 550
Index Keys 14: 583
Index Keys 15: 639
Index Keys 16: 677
Index Keys 17: 717
Index Keys 18: 768
Index Keys 19: 799
Index Keys 20: 831
Index Keys 21: 863
Index Keys 22: 895
Index Keys 23: 949
Index Keys 24: 984
Index Keys 25: 1017
Index Keys 26: 1063
Index Keys 27: 1117
Index Keys 28: 1164
Index Keys 29: 1214
Index Keys 30: 1275
Index Keys 31: 1337
Index Keys 32: 1391
Index Keys 33: 1446
Index Keys 34: 1507