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**CZ4031: DATABASE SYSTEM PRINCIPLES**

**Assignment 1**

***3 October 2021***

**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 108 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(uintptr\_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:

Number of records per block =

= **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 =
* Minimum number of keys in leaf node =

## 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, 106)
* 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

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

**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: 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:

Text

Description automatically generated

Graphical user interface

Description automatically generated

Text

Description automatically generated

## 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