COL106: Assignment 4

Trie, Red-Black tree and Priority queue

Updated: October 14, 2019

1 Fixes

- Please note some changes in the output format for Trie.

- **Allowed imports:** List, Stack and Queue.

Logistics:
Release date: September 13, 2019
Submission deadline: ~~30th September, 23:55~~ 2nd October, 23:55
Total marks: 5
PDF Version: Assignment 4 PDF
FAQ: See Section 8
Code can be downloaded from here : Download code
Changes:

- Download the new Makefile. Replace the current Makefile in the src folder with this one. This takes care of the file encoding issues while comparing.

- Constant files, the files that you are NOT suppose to change can be found here: Download constant files. Just replace these files in their respective directories. You can make changes to other files as per your requirements.

Brief description:
In this assignment you need to work with *Tries*, *Red-Black trees* and *Priority queues*. There will be **four** components of the assignment. The first three will check *tries, red-black trees* and *priority queues* independently. The last part of the assignment will be a combination of all the previous components.

2 General instructions

The grading will be done automatically. To ensure a smooth process, an interface will be provided to you, which you are **NOT** suppose to change. Your solution classes will implement these interfaces.

For each of the component, you will be given and *input* file, which will contain the commands that your code must execute. As per the command, the program will produce the *output*, which will be compared against an expected output for grading. Please ensure that you follow the proper formatting criteria, failing to do so will results in a penalty or no marks for that particular component.

2.1 Code skeleton

You are provided with the skeleton of the code. This contains the interfaces and other relevant information. Your task is to implement these functions. The code also contains *driver code* for all the components of assignment. These will be used to check the correctness of the code. Please **DO NOT** modify the interface and the driver code. You are free to change and implement other parts in any way you like.
Code can be downloaded from here: Download code

2.1.1 Building and Running

In the code, within the src folder, you can use the following commands to check your code.

```
make
```

This will check all the components. Components can also be checked independently:

```
make trie
make rbtree
make pq
make pm
```

for Trie, Red-Black tree, Priority-Queue and Project-Management (4th component) respectively.

3 Trie [1 Mark]

Trie is an efficient information reTrieval data structure. Using Trie, search complexities can be brought to optimal limit (key length) [3].
In this part of the assignment, you need to implement a Trie data structure. To make things interesting, you will be implementing a telephone directory using Tries. Name of a person will be the key (assuming all names are unique). Associate with every name will be a `Person` object.

```java
package Trie;
public class Person {
    public Person(String name, String phone_number) {
    }
```

```
5    public String getName() {
6        return "";
7    }
8 }
```

Listing 1: Person class.

3.1 Interface

You version of Trie must implement the TrieInterface as shown in Listing 2 and is also present in the code provided.

```
1  package Trie;
2  /**
3   * DO NOT EDIT THIS FILE.
4   */
5  public interface TrieInterface<T> {
6      /**
7       * @param word  Word to be input in the Trie
8       * @param value Associated value of the word
9       * @return Success or failure
10      */
11     boolean insert(String word, T value);
12     /**
13      * @param word Search for this word, Case-Sensitive
14      * @return Returns the Trienode associated if the word is
             found else NULL
15      */
16     TrieNode<T> search(String word);
17     /**
18      *
19      * @param prefix Search a particular prefix
20      * @return Returns the last Trienode associated with the
             prefix. Eg: If PARIS and PARROT is in the Tries,
             searching for PAR, returns the trienode of first R
21      */
22     TrieNode<T> startsWith(String prefix);
23     /**
24      *
25      * @param trieNode Prints all the possible word possible
             from this Trienode
26      *                 Eg: PAR and PARIS,
           printTrie(startWith("PAR")) should print PARIS and
```

```
               PARROT i.e all the words with suffix PAR
27       */
28      void printTrie(TrieNode trieNode);
29      /**
30       *
31       * @param word Delete a word from the Trie
32       * @return Success or Failure
33       */
34      boolean delete(String word);
35      /**
36       * Print the complete Trie
37       */
38      void print();
39      /**
40       * Print a specific level of the Trie.
41       *
42       * @param level
43       */
44      void printLevel(int level);
45  }
```

Listing 2: Interface specifications for Trie.

3.2 Input specifications

Commands:

1. INSERT: It takes a Person name and phone number (in next line) as input and inserts that into the trie.

2. DELETE: It takes a String as an input and deletes that from the trie.

3. SEARCH: It takes a String as input and returns *true* or *false*, based on whether that word is present in trie or now.

4. MATCH: It takes a String as an input, and return all words where the prefix is the entered String. *Printing is done in a lexicographical order*.

5. PRINTLEVEL: Print the specified level *in lexicographical order separated by comma and DO NOT print spaces*.

6. PRINT: Print all the *LEVELS* of the trie. The print format same as that of PRINTLEVEL.

Sample input file:

```
1   INSERT
2   Diljeet Singh, +91987654321
3   INSERT
4   Bhavesh Kumar, +91987654321
5   INSERT
6   Chayan Malhotra, +91987654321
7   INSERT
8   Ekta Mittal, +91987654321
9   INSERT
10  Farhan Khan, +91987654321
11  INSERT
12  Dishant Goyal, +91987654321
13  INSERT
14  Dishant Kumar, +91987654321
15  INSERT
16  Dishant Gupta, +91987654321
17  SEARCH
18  Dishant Goyal
19  MATCH Di
20  MATCH di
21  DELETE
22  Dishant Goyal
23  SEARCH
24  Dishant Goyal
25  MATCH SK
26  PRINTLEVEL 2
27  PRINT
28  DELETE
29  Dishant Goyal
```

Listing 3: Input for Trie.

Expected Output file:

```
1   Inserting: Diljeet Singh
2   Inserting: Bhavesh Kumar
3   Inserting: Chayan Malhotra
4   Inserting: Ekta Mittal
5   Inserting: Farhan Khan
6   Inserting: Dishant Goyal
7   Inserting: Dishant Kumar
8   Inserting: Dishant Gupta
9   Searching: Dishant Goyal
```

```
10   FOUND
11   [Name: Dishant Goyal, Phone=+91987654321]
12   Matching: Di
13   MATCHED:
14   [Name: Diljeet Singh, Phone=+91987654321]
15   [Name: Dishant Goyal, Phone=+91987654321]
16   [Name: Dishant Gupta, Phone=+91987654321]
17   [Name: Dishant Kumar, Phone=+91987654321]
18   Matching: di
19   NOT FOUND
20   Deleting: Dishant Goyal
21   DELETED
22   Searching: Dishant Goyal
23   NOT FOUND
24   Matching: SK
25   NOT FOUND
26   Level 2: a,h,h,i,k
27   -------------
28   Printing Trie
29   Level 1: B,C,D,E,F
30   Level 2: a,h,h,i,k
31   Level 3: a,a,l,r,s,t
32   Level 4: a,h,h,j,v,y
33   Level 5: a,a,a,e,e
34   Level 6: M,e,n,n,n,s
35   Level 7: h,i,t,t
36   Level 8: K,M,t
37   Level 9: G,K,K,S,a,h,t
38   Level 10: a,a,i,l,u,u,u
39   Level 11: h,l,m,m,n,n,p
40   Level 12: a,a,g,o,t
41   Level 13: a,h,r,r,t
42   Level 14: r
43   Level 15: a
44   Level 16:
45   -------------
46   Deleting: Dishant Goyal
47   ERROR DELETING
```

Listing 4: Ouput for Trie.

4 Red-Black Tree [1 Mark]

In this part you need to implement a Red-Black tree. A tutorial on Red-Black tree can be found here [2]. In this part, the basic operations on a Red-Black tree, insert and search will be tested. Note: you are not required to implement the *delete* feature. You will be given an input file, whose format is listed in Section 4.2. A sample output for the input command given in Section 4.2 is shown in 7
In this case also you will implement a telephone directory, with an extra feature that a person can have multiple numbers.

4.1 Specifications

You Red-Black tree, must implement the interface as shown in listing 5.

```
package RedBlack;
public interface RBTreeInterface<T extends Comparable, E> {
    /**
     * Insert and element using the "key" as the key and the
         corresponding value.
     * Please note that value is a generic type and it can be
         anything.
     *
     * @param key
     * @param value
     */
    void insert(T key, E value);
    /**
     * Search using the key.
     *
     * @param key
     * @return
     */
    RedBlackNode<T, E> search(T key);
}
```

Listing 5: Interface for Red-Black tree.

Things to keep in mind:

- All the items insert into the RB-Tree has a key and the corresponding value with it. In this version of Red-Black tree, a *key* can have multiple items. If we are trying to insert an element with a key which is already present in the tree, the value will get attached /appended to that key. This can be seen in the Listing 6.

4.2 Input specifications

Commands:

1. INSERT: Insert a Person into the tree.

2. SEARCH: Searches for a person in the tree.

Sample input (ignore the line numbers):

```
INSERT
Diljeet Singh, +91987654321
INSERT
Bhavesh Kumar, +91987654321
INSERT
Chayan Malhotra, +91987654321
INSERT
Ekta Mittal, +91987654321
INSERT
Farhan Khan, +91987654321
INSERT
Dishant Goyal, +91987654321
INSERT
Dishant Goyal, +91999999999
INSERT
Dishant Kumar, +91987654321
INSERT
Dishant Gupta, +91987654321
SEARCH
Dishant Goyal
SEARCH
Sandeep
```

Listing 6: Input for RedBlack Tree.

Expected Output (ignore the line numbers):

```
Inserting: Diljeet Singh
Inserting: Bhavesh Kumar
Inserting: Chayan Malhotra
Inserting: Ekta Mittal
Inserting: Farhan Khan
Inserting: Dishant Goyal
Inserting: Dishant Goyal
Inserting: Dishant Kumar
Inserting: Dishant Gupta
```

```
10  Searching for: Dishant Goyal
11  [Name: Dishant Goyal, Phone=+91987654321]
12  [Name: Dishant Goyal, Phone=+91999999999]
13  Searching for: Sandeep
14  Not Found
```

Listing 7: Output for RedBlack Tree.

5 Priority queues [1 Mark]

In this part you will be working with a *priority queue*. Specifically, you will be implementing a *max-heap* which is an implementation of priority queue.
You will need to implement a *marks scoring system* using Max Heap. This will contains, students name and their corresponding marks. The max-heap will use the marks to arrange the students, i.e. the student with the highest marks will be on the top.

5.1 Specifications

```
1  package PriorityQueue;
2  /**
3   * DO NOT EDIT
4   *
5   * @param <T>
6   */
7  public interface PriorityQueueInterface<T extends Comparable> {
8      /**
9       * @param element Insert and element to the Priority Queue
10      */
11     void insert(T element);
12     /**
13      * Extract the current maximum element from the Queue
14         (assuming a max heap).
15      * @return
16      */
17     T extractMax();
18  }
```

Listing 8: Interface for PriorityQueue.

Commands

1. INSERT

   name marks: Insert the student in the tree. Student name and marks are give in the next line. Students name will be unique.

2. EXTRACTMAX: Extract the student with highest marks and print it. Extract operations also removes this from the max-heap.

Sample input (ignore the line numbers):

```
1  INSERT
2  Diljeet Singh, 10
3  INSERT
4  Bhavesh Kumar, 100
5  INSERT
6  Dishant Kumar, 67
7  EXTRACTMAX
8  EXTRACTMAX
9  EXTRACTMAX
10 EXTRACTMAX
```

Listing 9: Input for PriorityQueue.

Expected Output (ignore the line numbers):

```
1  Inserting: Diljeet Singh
2  Inserting: Bhavesh Kumar
3  Inserting: Dishant Kumar
4  Student{name='Bhavesh Kumar', marks=100}
5  Student{name='Dishant Kumar', marks=67}
6  Student{name='Diljeet Singh', marks=10}
7  Heap is empty.
```

Listing 10: Output for PriorityQueue.

6   Project Management (Scheduler) [2 Marks]

In this part of the assignment you need to combine all the previous components of the assignment, Trie, Red-Black Tree and Priority Queue to implement a Job scheduler (Project management). The main part of this part are:

1. **Project:**
   The project class will be have a *name*, *budget* and *priority* (as shown in Listing 11).

```
1  package ProjectManagement;
2  public class Project {
```

```
3  }
```

Listing 11: Project class

2. **User:**

```
1  package ProjectManagement ;
2  public class User implements Comparable <User > {
3      @Override
4      public int compareTo (User user ) {
5          return 0;
6      }
7  }
```

Listing 12: User class

3. **Job:**

```
1  package ProjectManagement ;
2  public class Job implements Comparable <Job > {
3      @Override
4      public int compareTo (Job job ) {
5          return 0;
6      }
7  }
```

Listing 13: Job class

A job can have two status: REQUESTED, COMPLETED.

6.1 Specifications

The main component in this part of the assignment is a *Job*. As shown in Listing 13, each Job will belong to a Project and created by an User. The name of the Jobs will be unique (this is guaranteed in the test cases). All the jobs have a running time, i.e. the time required to run this job. The priority of a job is same as of that its project and a job can only be executed if its running time is less than the current budget of the Project. Successfully running a Job, will reduce the budget of that project by running time of the project.
All the projects will be stored in a Trie, using the project name as the *key*. Project names will be unique. All the Jobs will be stored in a *Priority Queue*, specifically a Max-Heap, using their priorities as the key.

6.2 Commands

A sample input file is shown in Listing 15.

11

1. USER: Create the user with given user name.

2. PROJECT: Create a project. NAME PRIORITY BUDGET

3. JOB: Create a job. NAME PROJECT USER RUNTIME

4. QUERY: Return the status of the Job queried.

5. ADD: Increase the budget of the project. PROJECT BUDGET

6. EMPTY_LINE: Let the scheduler execute a single JOB.

6.3   Scheduler specifications

The scheduler will execute a single job whenever it will encounter an empty line in the input specifications. After the end of the INP (input file) file, scheduler will continue to execute jobs till there are jobs left that can be executed.
Each time the scheduler wants to execute a job, it will do the following:

1. It selects the job with the highest priority from the MAX HEAP.

2. It first check the running time of the Job, say t.

3. It will then fetch the project from the RB-Tree and check its budget, say B.

4. If $B \geq t$ then it executes the job. Executing a job means:

   - Set the status of the job to complete.
   - Increase the global time by job time.
   - Set the completed time of the job as the current global time.
   - Decrease the budget of the project by run-time of the job. i.e. $\hat{B} = B - t$, where $\hat{B}$ is the new budget of the project.

5. If: $B < t$, then select the next job from the max-heap (where jobs are stored) and try to execute this.

6. A scheduler will return in following cases:

   - It successfully executed a single job.
   - There are no jobs to be executed.
   - None of the jobs can be executed because of the budget issue.

7. After the execution returns, process the next *batch* of commands (all the commands till next EMPTY_LINE or EOF).

8. If there are no more commands in the INP (input file) file, then let the scheduler execute jobs till there are no jobs left, or no jobs can be executed because of budget issues. This marks the END of the execution.

9. Print the stats of the current system. See Listing 16.

```java
package ProjectManagement;
/**
 * DO NOT MODIFY
 */
public interface SchedulerInterface {
    /**
     * @param cmd Handles Project creation. Input is the
     *    command from INP1 file in array format (use space to
     *    split it)
     */
    void handle_project(String[] cmd);
    /**
     * @param cmd Handles Job creation. Input is the command
     *    from INP1 file in array format (use space to split it)
     */
    void handle_job(String[] cmd);
    /**
     * @param name Handles user creation
     */
    void handle_user(String name);
    /**
     * Returns status of a job
     *
     * @param key
     */
    void handle_query(String key);
    /**
     * Next cycle, is executed whenever an empty line is found.
     */
    void handle_empty_line();
    /**
     * Executed as a thread to server a job.
     */
    void schedule();
    /**
     * Add budget to a project Input is the command from INP1
     *    file in array format (use space to split it)
```

```
34          *
35          * @param cmd
36          */
37         void handle_add(String[] cmd);
38         /**
39          * If there are no lines in the input commands, but there
                 are jobs which can be executed, let the system run till
                 there are no jobs left (which can be run).
40          */
41         void run_to_completion();
42         /**
43          * After execution is done, print the stats of teh system
44          */
45         void print_stats();
46 }
```

Listing 14: Interface specification

```
1  USER Rob
2  USER Harry
3  USER Carry
4  PROJECT IITD.CS.ML.ICML 10 15
5  PROJECT IITD.CS.OS.ASPLOS 9 100
6  PROJECT IITD.CS.TH.SODA 8 100
7  JOB DeepLearning IITD.CS.ML.ICML Rob 10
8  JOB ImageProcessing IITD.CS.ML.ICML Carry 10
9  JOB Pipeline IITD.CS.OS.ASPLOS Harry 10
10 JOB Kmeans IITD.CS.TH.SODA Carry 10
11
12 QUERY Kmeans
13 QUERY Doesnotexists
14
15 JOB DeepLearningNoProject IITD.CS.ML.ICM Rob 10
16 JOB DeepLearningNoUser IITD.CS.ML.ICML Rob2 10
17
18 JOB DeepLearning1 IITD.CS.ML.ICML Rob 10
19 JOB ImageProcessing1 IITD.CS.ML.ICML Carry 10
20 JOB Pipeline1 IITD.CS.OS.ASPLOS Harry 10
21 JOB Kmeans1 IITD.CS.TH.SODA Carry 10
22
23 JOB DeepLearning2 IITD.CS.ML.ICML Rob 10
24 JOB ImageProcessing2 IITD.CS.ML.ICML Carry 10
25 JOB Pipeline2 IITD.CS.OS.ASPLOS Harry 10
```

```
26  JOB Kmeans3 IITD.CS.TH.SODA Carry 10
27
28  ADD IITD.CS.ML.ICML 60
29  JOB DeepLearning3 IITD.CS.ML.ICML Rob 10
30  JOB ImageProcessing3 IITD.CS.ML.ICML Carry 10
31  JOB Pipeline3 IITD.CS.OS.ASPLOS Harry 10
32  JOB Kmeans3 IITD.CS.TH.SODA Carry 10
33
34  QUERY Kmeans
35
36  JOB DeepLearning4 IITD.CS.ML.ICML Rob 10
37  JOB ImageProcessing4 IITD.CS.ML.ICML Carry 10
38  JOB Pipeline4 IITD.CS.OS.ASPLOS Harry 10
39  JOB Kmeans4 IITD.CS.TH.SODA Carry 10
40
41  JOB DeepLearning5 IITD.CS.ML.ICML Rob 10
42  JOB ImageProcessing5 IITD.CS.ML.ICML Carry 10
43  JOB Pipeline5 IITD.CS.OS.ASPLOS Harry 10
44  JOB Kmeans5 IITD.CS.TH.SODA Carry 10
45
46  QUERY Kmeans
```

Listing 15: Input specification

```
1   Creating user
2   Creating user
3   Creating user
4   Creating project
5   Creating project
6   Creating project
7   Creating job
8   Creating job
9   Creating job
10  Creating job
11  Running code
12  Remaining jobs: 4
13  Executing: DeepLearning from: IITD.CS.ML.ICML
14  Project: IITD.CS.ML.ICML budget remaining: 5
15  Execution cycle completed
16  Querying
17  Kmeans: NOT FINISHED
18  Querying
19  Doesnotexists: NO SUCH JOB
```

```
20  Running code
21  Remaining jobs: 3
22  Executing: ImageProcessing from: IITD.CS.ML.ICML
23  Un-sufficient budget.
24  Executing: Pipeline from: IITD.CS.OS.ASPLOS
25  Project: IITD.CS.OS.ASPLOS budget remaining: 90
26  Execution cycle completed
27  Creating job
28  No such project exists. IITD.CS.ML.ICM
29  Creating job
30  No such user exists: Rob2
31  Running code
32  Remaining jobs: 1
33  Executing: Kmeans from: IITD.CS.TH.SODA
34  Project: IITD.CS.TH.SODA budget remaining: 90
35  Execution cycle completed
36  Creating job
37  Creating job
38  Creating job
39  Creating job
40  Running code
41  Remaining jobs: 4
42  Executing: DeepLearning1 from: IITD.CS.ML.ICML
43  Un-sufficient budget.
44  Executing: ImageProcessing1 from: IITD.CS.ML.ICML
45  Un-sufficient budget.
46  Executing: Pipeline1 from: IITD.CS.OS.ASPLOS
47  Project: IITD.CS.OS.ASPLOS budget remaining: 80
48  Execution cycle completed
49  Creating job
50  Creating job
51  Creating job
52  Creating job
53  Running code
54  Remaining jobs: 5
55  Executing: DeepLearning2 from: IITD.CS.ML.ICML
56  Un-sufficient budget.
57  Executing: ImageProcessing2 from: IITD.CS.ML.ICML
58  Un-sufficient budget.
59  Executing: Pipeline2 from: IITD.CS.OS.ASPLOS
60  Project: IITD.CS.OS.ASPLOS budget remaining: 70
61  Execution cycle completed
```

```
62  ADDING Budget
63  Creating job
64  Creating job
65  Creating job
66  Creating job
67  Running code
68  Remaining jobs: 11
69  Executing: ImageProcessing from: IITD.CS.ML.ICML
70  Project: IITD.CS.ML.ICML budget remaining: 55
71  Execution cycle completed
72  Querying
73  Kmeans: COMPLETED
74  Running code
75  Remaining jobs: 10
76  Executing: DeepLearning1 from: IITD.CS.ML.ICML
77  Project: IITD.CS.ML.ICML budget remaining: 45
78  Execution cycle completed
79  Creating job
80  Creating job
81  Creating job
82  Creating job
83  Running code
84  Remaining jobs: 13
85  Executing: ImageProcessing1 from: IITD.CS.ML.ICML
86  Project: IITD.CS.ML.ICML budget remaining: 35
87  Execution cycle completed
88  Creating job
89  Creating job
90  Creating job
91  Creating job
92  Running code
93  Remaining jobs: 16
94  Executing: DeepLearning2 from: IITD.CS.ML.ICML
95  Project: IITD.CS.ML.ICML budget remaining: 25
96  Execution cycle completed
97  Querying
98  Kmeans: COMPLETED
99  Running code
100 Remaining jobs: 15
101 Executing: ImageProcessing2 from: IITD.CS.ML.ICML
102 Project: IITD.CS.ML.ICML budget remaining: 15
103 System execution completed
```

```
104  Running code
105  Remaining jobs: 14
106  Executing: DeepLearning3 from: IITD.CS.ML.ICML
107  Project: IITD.CS.ML.ICML budget remaining: 5
108  System execution completed
109  Running code
110  Remaining jobs: 13
111  Executing: ImageProcessing3 from: IITD.CS.ML.ICML
112  Un-sufficient budget.
113  Executing: DeepLearning4 from: IITD.CS.ML.ICML
114  Un-sufficient budget.
115  Executing: ImageProcessing4 from: IITD.CS.ML.ICML
116  Un-sufficient budget.
117  Executing: DeepLearning5 from: IITD.CS.ML.ICML
118  Un-sufficient budget.
119  Executing: ImageProcessing5 from: IITD.CS.ML.ICML
120  Un-sufficient budget.
121  Executing: Pipeline3 from: IITD.CS.OS.ASPLOS
122  Project: IITD.CS.OS.ASPLOS budget remaining: 60
123  System execution completed
124  Running code
125  Remaining jobs: 7
126  Executing: Pipeline4 from: IITD.CS.OS.ASPLOS
127  Project: IITD.CS.OS.ASPLOS budget remaining: 50
128  System execution completed
129  Running code
130  Remaining jobs: 6
131  Executing: Pipeline5 from: IITD.CS.OS.ASPLOS
132  Project: IITD.CS.OS.ASPLOS budget remaining: 40
133  System execution completed
134  Running code
135  Remaining jobs: 5
136  Executing: Kmeans1 from: IITD.CS.TH.SODA
137  Project: IITD.CS.TH.SODA budget remaining: 80
138  System execution completed
139  Running code
140  Remaining jobs: 4
141  Executing: Kmeans3 from: IITD.CS.TH.SODA
142  Project: IITD.CS.TH.SODA budget remaining: 70
143  System execution completed
144  Running code
145  Remaining jobs: 3
```

```
146  Executing: Kmeans3 from: IITD.CS.TH.SODA
147  Project: IITD.CS.TH.SODA budget remaining: 60
148  System execution completed
149  Running code
150  Remaining jobs: 2
151  Executing: Kmeans4 from: IITD.CS.TH.SODA
152  Project: IITD.CS.TH.SODA budget remaining: 50
153  System execution completed
154  Running code
155  Remaining jobs: 1
156  Executing: Kmeans5 from: IITD.CS.TH.SODA
157  Project: IITD.CS.TH.SODA budget remaining: 40
158  System execution completed
159  -------------STATS--------------
160  Total jobs done: 19
161  Job{user='Rob', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=10,
        name='DeepLearning'}
162  Job{user='Harry', project='IITD.CS.OS.ASPLOS',
        jobstatus=COMPLETED, execution_time=10, end_time=20,
        name='Pipeline'}
163  Job{user='Carry', project='IITD.CS.TH.SODA',
        jobstatus=COMPLETED, execution_time=10, end_time=30,
        name='Kmeans'}
164  Job{user='Harry', project='IITD.CS.OS.ASPLOS',
        jobstatus=COMPLETED, execution_time=10, end_time=40,
        name='Pipeline1'}
165  Job{user='Harry', project='IITD.CS.OS.ASPLOS',
        jobstatus=COMPLETED, execution_time=10, end_time=50,
        name='Pipeline2'}
166  Job{user='Carry', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=60,
        name='ImageProcessing'}
167  Job{user='Rob', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=70,
        name='DeepLearning1'}
168  Job{user='Carry', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=80,
        name='ImageProcessing1'}
169  Job{user='Rob', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=90,
        name='DeepLearning2'}
```

```
170  Job{user='Carry', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=100,
        name='ImageProcessing2'}
171  Job{user='Rob', project='IITD.CS.ML.ICML',
        jobstatus=COMPLETED, execution_time=10, end_time=110,
        name='DeepLearning3'}
172  Job{user='Harry', project='IITD.CS.OS.ASPLOS',
        jobstatus=COMPLETED, execution_time=10, end_time=120,
        name='Pipeline3'}
173  Job{user='Harry', project='IITD.CS.OS.ASPLOS',
        jobstatus=COMPLETED, execution_time=10, end_time=130,
        name='Pipeline4'}
174  Job{user='Harry', project='IITD.CS.OS.ASPLOS',
        jobstatus=COMPLETED, execution_time=10, end_time=140,
        name='Pipeline5'}
175  Job{user='Carry', project='IITD.CS.TH.SODA',
        jobstatus=COMPLETED, execution_time=10, end_time=150,
        name='Kmeans1'}
176  Job{user='Carry', project='IITD.CS.TH.SODA',
        jobstatus=COMPLETED, execution_time=10, end_time=160,
        name='Kmeans3'}
177  Job{user='Carry', project='IITD.CS.TH.SODA',
        jobstatus=COMPLETED, execution_time=10, end_time=170,
        name='Kmeans3'}
178  Job{user='Carry', project='IITD.CS.TH.SODA',
        jobstatus=COMPLETED, execution_time=10, end_time=180,
        name='Kmeans4'}
179  Job{user='Carry', project='IITD.CS.TH.SODA',
        jobstatus=COMPLETED, execution_time=10, end_time=190,
        name='Kmeans5'}
180  -----------------------
181  Unfinished jobs:
182  Job{user='Carry', project='IITD.CS.ML.ICML',
        jobstatus=REQUESTED, execution_time=10, end_time=null,
        name='ImageProcessing3'}
183  Job{user='Rob', project='IITD.CS.ML.ICML',
        jobstatus=REQUESTED, execution_time=10, end_time=null,
        name='DeepLearning4'}
184  Job{user='Carry', project='IITD.CS.ML.ICML',
        jobstatus=REQUESTED, execution_time=10, end_time=null,
        name='ImageProcessing4'}
185  Job{user='Rob', project='IITD.CS.ML.ICML',
```

```
      jobstatus=REQUESTED, execution_time=10, end_time=null,
      name='DeepLearning5'}
186 Job{user='Carry', project='IITD.CS.ML.ICML',
      jobstatus=REQUESTED, execution_time=10, end_time=null,
      name='ImageProcessing5'}
187 Total unfinished jobs: 5
188 --------------STATS DONE---------------
```

Listing 16: Output for INP in Listing 15

7 Submission instructions

As always compress *src* directory to zip format and rename the zip file in the format
entrynumber_assignment4.zip. For example, if your entry number is 2012CSZ8019, the zip
file should be named 2012CSZ8019_assignment4.zip. Then you need to convert this zip
file to base64 format as follows and submit the .b64 file on Moodle.

```
base64 entrynumber_assignment4.zip > entrynumber_assignment4.zip.b64
```

Folder structure: Inside the src directory, you need to have a README.pdf (case sensitive)
and your solution (exactly following the folder structure that of the code provided.). Please
do not rename the existing directories. You need to report the time complexities of various
operations for both the implementations. You should also report any interesting findings
based on your experiments with the two implementations.

Grading: While grading we will replace the *driver code* and the *interface* code with the
original files before the compilation. So please ensure that your code compiles and run
correctly with the original driver and interface files.

MOSS: Please note that we will run MOSS on the submitted code. Anyone found with a
copied code, either from Internet or from another student, will be dealt as per the class
policy.

8 FAQ

- See some fixes here: 1

- Project Management: In what data-structure projects are stored?
  Ans: Trie

- Trie: Match: match the search term with *pre-fix* of entries.

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- Lists and its subclasses (ArrayList, LinkedList) etc. are allowed.

- Maps (e.g. HashMap) are also allowed.

- You need to override the *toString()* method in classes to print in a particular format.

- Printing order in Trie: Lexicographical order. DO NOT print spaces (which is present in the name). You need to store spaces in the Trie, otherwise MATCH command will print first-name and second-name together(without a space) and it will not match the output.

- Trie: Names can contain any character whose ASCII code is between **32-126**, see an ASCII table here: [1].

- Trie: If a particular entry is not found, print `NOT FOUND`.

- Build issues: Please use the `Makefile` provided.

- Only List, Stack, Queue and *Maps* arze allowed to be imported.

- There are some encoding issue in file compare. We are working on it.

- Extract-Max in Priority Queue should follow FIFO (if the priority of two objects is same).

- Casting from and to Object is allowed.

- Please adhere to return types of the function. It will be used in the driver code.

- You can use Iterator.

- Print: Trie. Last level is empty, which represents the end of the Trie.

- Question: Adding budget to a project, what to do with its unfinished (but already tried) jobs?
  Answer: https://piazza.com/class/jyic9aa2xyb34g?cid=649

- Project insertion and retrieval doubt: We are inserting project in a trie and retrieving from a RB tree, how?
  Answer:When a new Project is created, it is stored in a Trie. RB-Tree is used as a NOT_READY queue. To store the jobs which cannot be executed because there is not enough budget left. As mentioned in the RB-Tree implementation, using a single key we can store multiple objects.

- Files NOT to be edited: Please make no changes to the Driver code for the Trie, RedBlack and PriorityQueue. And please do not change any of the interface files.

- Size of Max-heap: Upper bound on the size of the heap: 10000. You can use lists.

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- Project management, empty_line, run_to_completion:

  ```
  "1. How is schedule() different from handle_empty_line()?"
  ```

  ```
  handle_empty_line is there so do dome pre-processing before calling schedule.
  If you feel like this is not required, use this:
  ```

  ```
  public void handle_empty_line() {
  schedule();
  }
  ```

  ```
  "2. What is the use of run()? What is schedule() doing inside that?
   If it is for completing the pending jobs at the end, then why
   run_to_completion()?"
  ```

  ```
  The driver uses a thread to execute the jobs. schedule() contains
  the logic to check the budget, then either execute the code or move
   it to a NON_READY queue.
  As can be seen from the driver code, run_to_completion() is used
   when we are done processing the INPUT FILE (i.e. no more
  commands are left to process).
  ```

- What to return in RBTree when key is not found?
  A RedBlackNode with NULL key and NULL values.

- If a key has multiple values associates with it, then the output of search query for that key should have values printed in lexicographic order or FIFO.

- Priority order:
  FIFO order comes after priority.
  If there are two jobs with a different priority, then you take the job which has the higher priority, irrespective of who came first.
  FIFO has to be maintained only if their priorities are same.

- *print_stats* specification: After the system is done with executing all the commands, it tries to executed as many job it can. Once it is done with that, it prints the stats of the system and exists. The order of printing:

  1. Print all the executed job first in the order which they were executed. The job executed first should be printed first.

2. After this print all the un-finished job. At this point, the *waiting-queue* or the MAX-HEAP used by the scheduler to find the job should be empty. Jobs must have been completed or will be in the *NOT_READY* queue.
Printing order:

   - Process projects based on their priority.
   - Processing a project means, printing all the jobs belonging to that project.
   - Project priority is determined in the same way as that of the jobs. The project having a higher value of the "priority" has the higher priority. If the value of the priorities is same, then the project created first has the higher priority.
   - With-in a project: Print jobs based on their priority. See `Priority order` in this FAQ to decide priority of a job.

References

[1] Ascii table - ascii character codes and html, octal, hex and decimal chart conversion. `http://www.asciitable.com/`. (Accessed on 09/15/2019).

[2] Painting nodes black with red-black trees - basecs - medium. `https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5`. (Accessed on 09/10/2019).

[3] Trie — (insert and search) - geeksforgeeks. `https://www.geeksforgeeks.org/trie-insert-and-search/`. (Accessed on 09/12/2019).