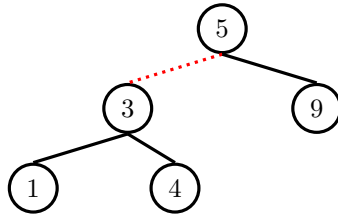


1 LLRB Insertions

Given the LLRB below, perform the following insertions and draw the final state of the LLRB. In addition, for each insertion, write the balancing operations needed in the correct order (rotate right, rotate left, or color flip). If no balancing operations are needed, write "Nothing". Assume that the link between 5 and 3 is red and all other links are black at the start.

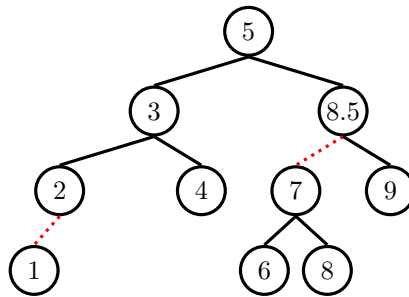


- (a)
1. Insert 7
 2. Insert 6
 3. Insert 2
 4. Insert 8
 5. Insert 8.5
 6. Final state

Solution: For a visualization of the process, see [here](#)

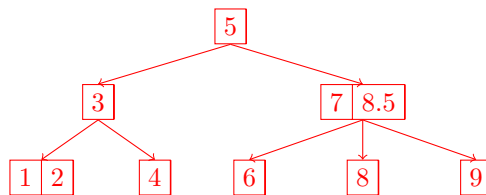
1. Insert 7
 - Nothing
2. Insert 6
 - rotateRight(9)

- colorFlip(7)
 - colorFlip(5)
3. Insert 2
 - rotateLeft(1)
 4. Insert 8
 - Nothing
 5. Insert 8.5
 - rotateLeft(8)
 - rotateRight(9)
 - colorFlip(8.5)
 - rotateLeft(7)
 6. Final state:



(b) Convert the final LLRB to its corresponding 2-3 Tree.

Solution:



2 Hashing Gone Crazy

For this question, use the following TA class for reference.

```
public class TA {
    int semester;
    String name;
    TA(String name, int semester) {
        this.name = name;
        this.semester = semester;
    }
    @Override
    public boolean equals(Object o) {
        TA other = (TA) o;
        return other.name.charAt(0) == this.name.charAt(0);
    }
    @Override
    public int hashCode() { return semester; }
}
```

Assume that the ECHashMap is a HashMap implemented with **external chaining** as depicted in lecture. The ECHashMap instance begins with 4 buckets.

Resizing Behavior If an insertion causes the load factor to reach or exceed 1, we resize by doubling the number of buckets. During resizing, we traverse the linked list that correspond to bucket 0 to rehash items one by one, and then traverse bucket 1, bucket 2, and so on. Duplicates are **not** checked when rehashing into new buckets.

Draw the contents of map after the executing the insertions below:

```
1    ECHashMap<TA, Integer> map = new ECHashMap<>();
2    TA jasmine = new TA("Jasmine the GOAT", 10);
3    TA noah = new TA("Noah", 20);
4    map.put(jasmine, 1);
5    map.put(noah, 2);
6
7    noah.semester += 2;
8    map.put(noah, 3);
9
10   jasmine.name = "Nasmine";
11   map.put(noah, 4);
12
13   jasmine.semester += 2;
14   map.put(jasmine, 5);
15
16   jasmine.name = "Jasmine";
17   TA cheeseguy = new TA("Sam", 24);
18   map.put(cheeseguy, 6);
```

Solution:

2 Hashing Gone Crazy - Resizing!

```

EHashMap<TA, Integer> map = new EHashMap<>();
TA jasmine = new TA("Jasmine the GOAT", 10);
TA noah = new TA("Noah", 20);
map.put(jasmine, 1);
map.put(noah, 2);

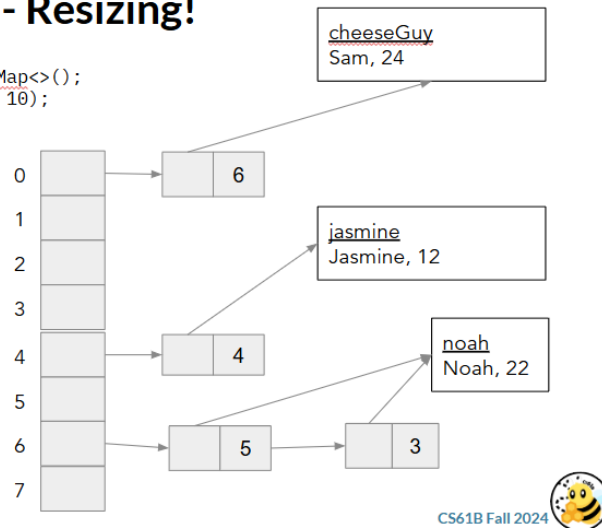
noah.semester += 2;
map.put(noah, 3);

jasmine.name = "Nasmine";
map.put(noah, 4);

jasmine.semester += 2;
map.put(jasmine, 5);

jasmine.name = "Jasmine";
TA cheeseGuy = new TA("Sam", 24);
map.put(cheeseGuy, 6);

```

**Explanation:**

Line 4: jasmine has semester value 10. $10 \% 4 = 2$, so jasmine is placed in bucket 2 with value 1.

0: [], 1: [], 2: [(jasmine, 1)], 3: []

Line 5: noah is placed in bucket 0 with value 2.

0: [(noah, 2)], 1: [], 2: [(jasmine, 1)], 3: []

Line 7: Increasing the semester value of noah does *not* cause it to be rehashed! (This is why modifying objects in a Hashmap is dangerous—it can change the hashcode of your object and make it impossible to find which bucket it belongs to).

Line 8: noah now has semester 4, so bucket 2 also has a node pointing to noah, with value 3. (Note that the two noahs refer to the same object).

0: [(noah, 2)], 1: [], 2: [(jasmine, 1), (noah, 3)], 3: []

Line 11, 12: noah with semester 22 hashes to bucket 2. However, since we have changed jasmine's name to be "Nasmine", `noah.equals(jasmine)` returns true. Since we are hashing a key that is already present in the dictionary according to `.equals`, we replace jasmine's old value with the new value, 4.

0: [(noah, 2)], 1: [], 2: [(jasmine, 4), (noah, 3)], 3: []

Line 13, 14: jasmine with semester 12 hashes to bucket 0. However, since we have changed jasmine's name to be "Nasmine", `jasmine.equals(noah)` returns true. Since we are hashing a key that is already present in the dictionary according to `.equals`, we replace noah's old value with the new value, 5.

0: [(noah, 5)], 1: [], 2: [(jasmine, 4), (noah, 3)], 3: []

Line 16, 17, 18: cheeseGuy hashes to bucket 0. `cheeseGuy.equals(noah)` returns false, so we add a new node after noah with value 6.

0: [(noah, 5), (cheeseGuy, 6)], 1: [], 2: [(jasmine, 4), (noah, 3)], 3: []

Resizing: The load factor reaches 1, and we resize to 8 buckets. We rehash the elements in the order they were inserted, so the final state of the map is:

Notice that duplicates are not checked when rehashing into new buckets, therefore, the noah object is inserted twice.

3 Buggy Hash

The following classes may contain a bug in one of its methods. Identify those errors and briefly explain why they are incorrect and in which situations would the bug cause problems.

(a) The Timezone class below:

```

1      class Timezone {
2          String timeZone; // "PST", "EST" etc.
3          boolean dayLight;
4          String location;
5          ...
6          public int currentTime() {
7              // return the current time in that time zone
8          }
9          public int hashCode() {
10             return currentTime();
11         }
12         public boolean equals(Object o) {
13             Timezone tz = (Timezone) o;
14             return tz.timeZone.equals(timeZone);
15         }
16     }

```

Solution:

Although equal objects will have the same hashCode, but the problem here is that hashCode() is not deterministic. This may result in weird behaviors (e.g. the element getting lost) when we try to put or access elements.

(b) The Course class below:

```

1      class Course {
2          int courseCode;
3          int yearOffered;
4          String[] staff;
5          ...
6          public int hashCode() {
7              return yearOffered + courseCode;
8          }
9          public boolean equals(Object o) {
10             Course c = (Course) o;
11             return c.courseCode == courseCode;
12         }
13     }

```

Solution: The problem with this hashCode() is that not all equal objects have the same hashCode. This may produce unexpected behavior, e.g. multiple "equal" objects may exist in different buckets in the HashMap, the containsKey operation may return false, etc. One key thing to remember is that when we override the equals() method, we have to also override the hashCode() method to ensure equal objects have the same hashCode.