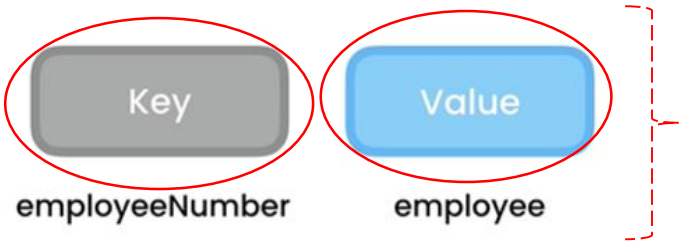
Hash Tables/Dictionaries-(Super-Fast Lookup)

V-(1+2)-HashTables?

HASH TABLES

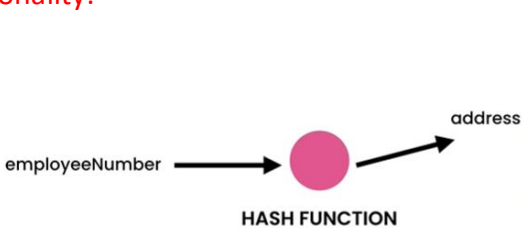
- Spell checkers
- Dictionaries
- Compilers
- Code editors

IMPLEMENTATIONS



Hash Table Attributes

Functionality:-



Deterministic

Same Input Same Value Always

Its super-fast and it return same value for same input that's why we use hash tables for storing and retrieving data's.[Internally Hash Table use array's]

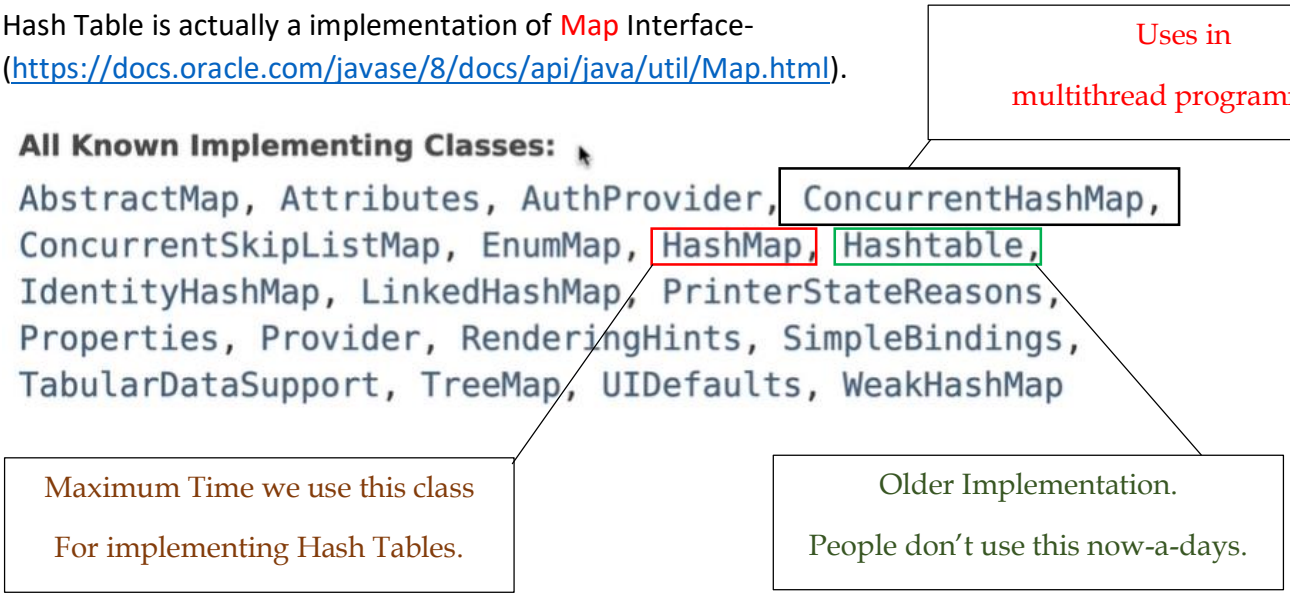
HASH TABLES

Insert	O(1)
Lookup	O(1)
Delete	O(1)

As Hash Table use arrays for implementation that's why we don't have to iterate the whole array. Many people had contradiction but most of them came to this conclusion of time complexities to be O(1).

(V-3)-(Working with Hash Tables):-

Hash Table is actually a implementation of Map Interface-
(https://docs.oracle.com/javase/8/docs/api/java/util/Map.html).

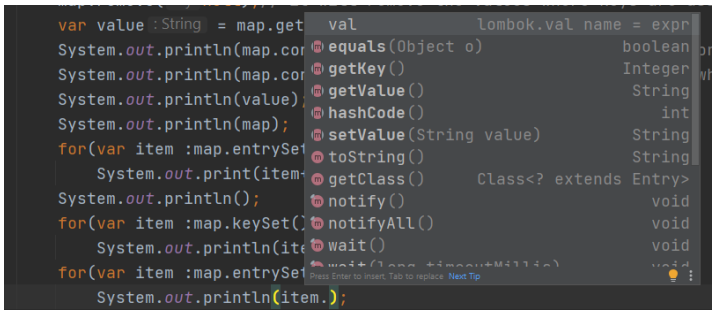


Basic methods(must) of HashMaps:-

```
import java.util.HashMap;
import java.util.Map;
// This main class has very basic implementation using
built in methods in Hash Map
public class Main {
    public static void main(String[] args) {
        // Key : employee Number (Integer)
        // Value: Name (String)
        Map<Integer, String> map = new HashMap<>();
        map.put(1,"Rakib");// adding items method
        map.put(2,"Sadman");
        map.put(3,"Nabik");
        map.put(3,"Abrar");// this will override value
of key ==> 3
        // in interview they ask if map can store both
key and value as null
        // So, it can store both null value in map
        map.put(4,null);
        map.put(null,null);
        map.remove(null);// it will remove the values
```

```
where keys are assigned null
        var value = map.get(3);// it will return a
String as our key value pair is <Integer,String>
        System.out.println(map.containsKey(3));// O(1)
==> fixed address for storing and retriving  the value

System.out.println(map.containsValue("Nabik"));//O(n)
==> iterate whole array and compare value with each
keys
        System.out.println(value);// it will give Abrar
        System.out.println(map);
        for(var item :map.entrySet())// print key value
pair
            System.out.print(item+" ");
        System.out.println();
        for(var item :map.keySet())// print the keys
only
            System.out.println(item+" ");
    }
}
```



Hash Table Methods(extra)

V-(4 + 5):-[First Non_Repeated Character]:-[Most Popular Interview question]

```
import java.util.HashMap;
import java.util.Map;

public class CharFinder {
    //popular interview question
    // Find first non repeated character from a given String.
    // String = "a green apple"
    // So, for the given example it is 'g'
    // This is a good exercise for hashmap
    // a green apple from this we build hashmap
    // a = 2
```

```
    //    = 2
    // g = 1 etc for the whole string and return the first
character with an occurance of 1
    public char findFirstNonRepeatingChar(String str){
        Map<Character,Integer> map = new HashMap<>();
        var chars = str.toCharArray();
        for(char ch:chars){//full string iterated using
chararray
            //if character is got multiple times then count
value will be incremented by 1 otherwise it will set to 0
            var count = map.containsKey(ch)? map.get(ch):0;
            map.put(ch,count+1);

        }
       // System.out.println(map);
        // now check if it had only one occourance
        for (char ch :chars){
            if(map.get(ch)==1)// occurance 1 first return
                return ch;
        }
        return Character.MIN_VALUE;// if all characters are
repeated.
    }
}
```

V-6): Sets

HashTable : Key ➔ Value but Set: Unique Values.

Details of Set interface: (https://docs.oracle.com/javase/7/docs/api/java/util/Set.html)

All Known Implementing Classes:

AbstractSet, ConcurrentSkipListSet, CopyOnWriteArraySet, EnumSet, HashSet, JobStateReasons, LinkedHashSet, TreeSet

Among all the classes implemented with sets we just have to use HashSet in maximum real life implementation.

V-(7+8)First Repeated Character:-

```
public char findfirstRepeatedCharacter(String str){
// We can solve this using set, cause set willnot
contain any repeated value
    java.util.Set<Character> set = new HashSet<>();
    for(char ch:str.toCharArray()){//covert string to
chararray
        if(set.contains(ch))//check if it is already in
the set if it already exist then immidiately return it
and thats our first repeated character
            return ch;
        set.add(ch);
    }
    return Character.MIN_VALUE;
}
```

V-(9)-Hash Function:-

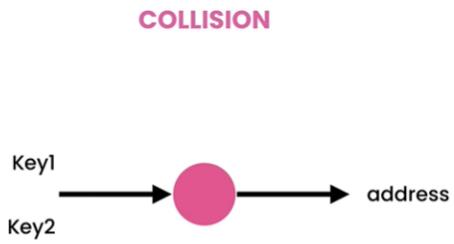
```
import java.util.HashMap;
import java.util.HashSet;
import java.util.Map;

public class Hashing {
    public static void main(String[] args) {
        Map<Integer,String> map = new HashMap<>();
        map.put(167546,"Rakib");
        //Now we have a limited array of 100 items
        // so we can't declare a an array of 167546
(not needed)
        // We can use hashing
        // though the key value is represented using a
big int value we can simplify it using mod

        System.out.println(hash(167546));
        //output for 167546 is 46 for hash method that
means
        // if we want to save the key value pair in an
array of 100 it should be in the 46th index
        Map<String,String> map1 = new HashMap<>();
        map1.put("1234567-A","Rakib");
        System.out.println(map1);
        System.out.println(hashString("1234567-A"));
        Map<Integer,String> rakibul = new HashMap<>();
        rakibul.put(1,"Ra*765kib");
```

```
        //items[1]=Ra*765kib;
        System.out.println(hashString("Ra*765kib"));
        //{1,Ra*765kib}
    }
    public static int hash(int number){
        return number%100;
    }
    public static int hashString(String key){
        int hash = 0;
        for(var ch:key.toCharArray())
            hash+=ch;// this is an implicit casting
        //as all the characters are represented by a
number
        // though we add an integer with an character
but character is coverted
        // to an integer and added with hash which is
also an integer
        return hash%100;
    }
}
```

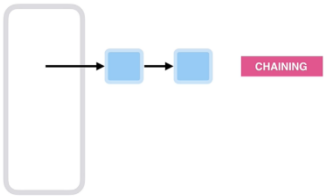
V-(10)Collision:-



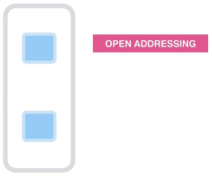
Two separate keys want to store Same Value That generate Collision.

Two ways to solve this collision problem.

1. Chaining:-(Use Linked List instead of array and if collision happened then add the value next to the value (Collision with))

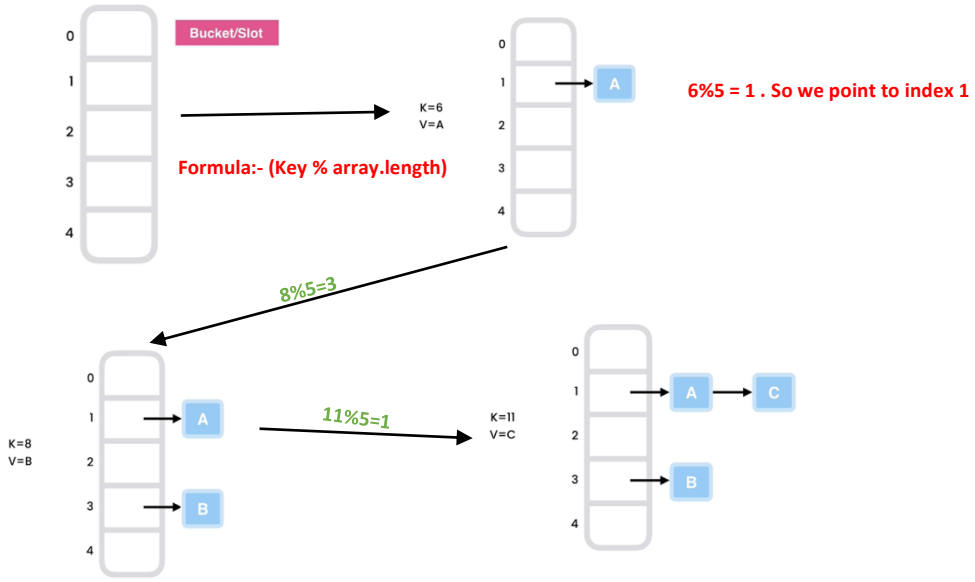


2. Open Addressing :-(Here we have to generate new address for storing the value(Collision with)

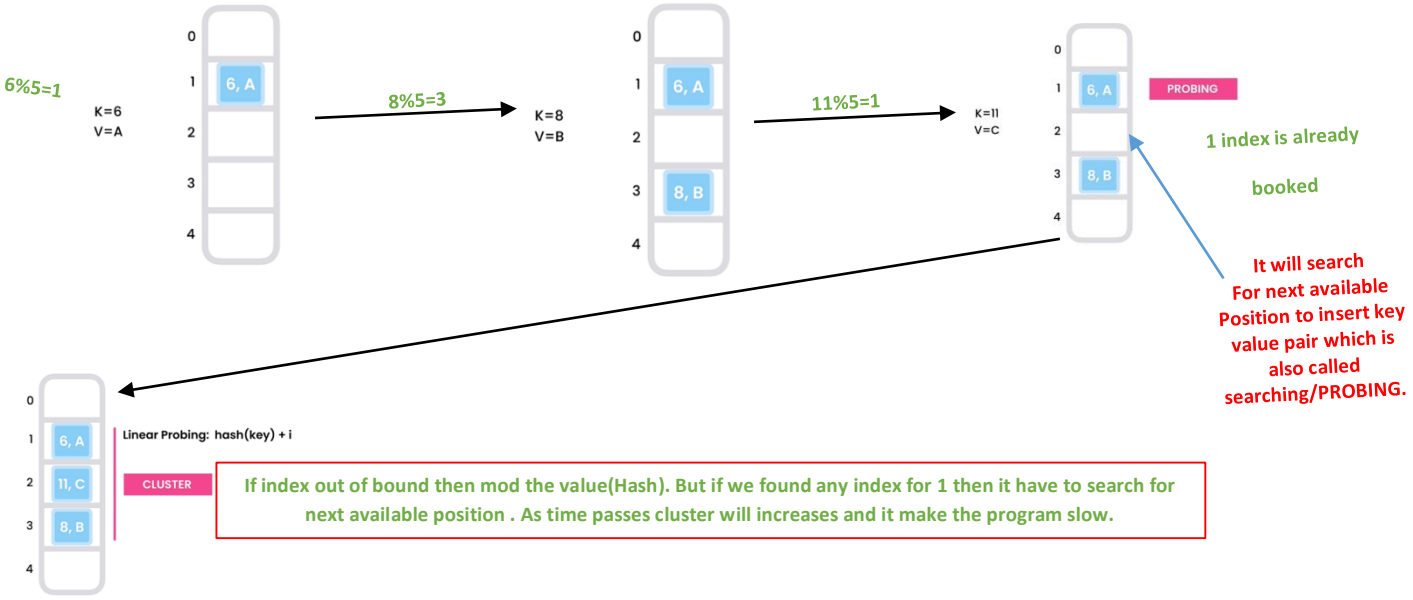


V-(11)-Chaining:-

We don't directly inserted to the remainder (index) instead we point that index and built Linked List.



V-(12)-Open Addressing-(method1-Linear Probing):-



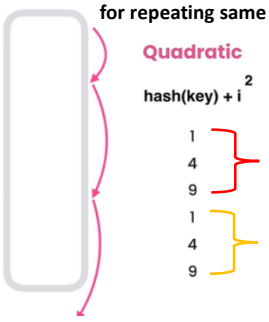
V-(13)-Open Addressing-(method2-Quadratic Probing):-

Quadratic Mean Square.

$$(hash(key) + i^2) \% table\_size$$

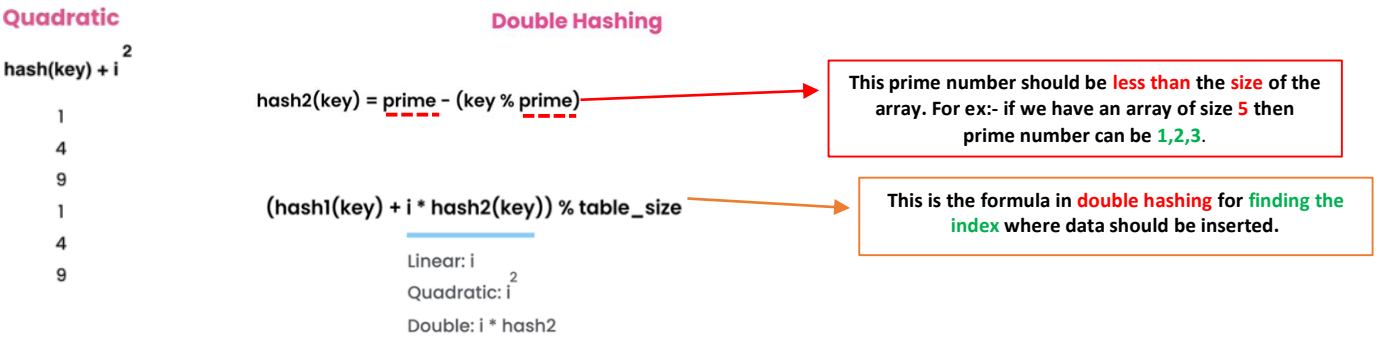
We just change the formula for finding the address where data will be allocated it is faster than linear probing but it has a problem also. As we take big jumps for finding next position we may ended up in infinite loop for repeating same steps.

Linear	Quadratic
hash(key) + i	hash(key) + i^2
1	1
2	4
3	9
4	16
5	25

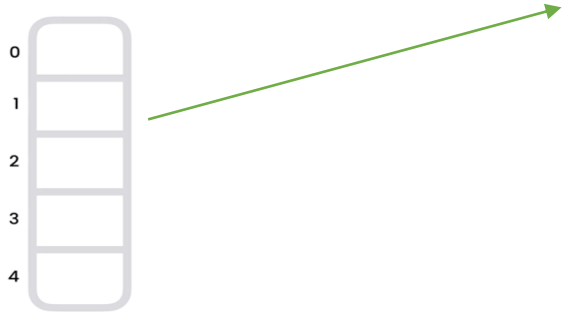


V-(14)-Open Addressing-(method3-Double Hashing):-

As Quadratic has infinite loop problem we can solve it using double hashing .



Now , Let's see double hash in **Action.**



Before starting:-

Double Hashing Formulas:-

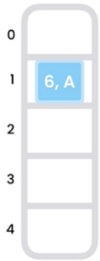
1. hash1(key) = key % table_size.

2. hash2(key) = prime – (key % prime). In our example it should be 3 cause array size is 5 and indices are [0-4]. Between this range we have to select prime numbers. Its ideal to select the largest but less than the range of array could be okay . So we choose 3 as our prime number for double hashing. So our 1 no. formula is hash2(key) = 3 – (key % 3).

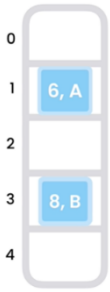
3. (hash1(key)+i*hash2(key)) % table_size.

We will use the following two formulas if collison occur.

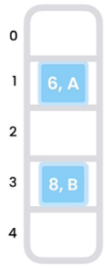
Now lets start to insert key value pairs in the given array. If this is the first key-value pair {K=6,V=A} then key % array_size = 6 % 5 = 1. Then we should insert it in the 1 number index like below:-



Secondly, if key-value pair {K=8,V=B} then key % array_size = 8 % 5 = 3. Then we should insert it in the 3 number index like below:-



Thirdly, if key-value pair {K=11,V=C} then key % array_size = 11 % 5 = 1 [using no. 1 formula of double hashing]. As number 1 index has already store a key-value pair {6,A}. That means collision occur. Now we will use double hashing.



Double hashing formulas:-

1. **hash1(key) = key % table_size.**

2. **hash2(key) = prime – (key % prime). [we already select 3 as prime number for this problem.]**

3. **(hash1(key)+i*hash2(key)) % table_size.**

key-value pair {K=11,V=C}

Calculations (after finding collsion):-

hash2(11) = 3 – (11 % 3)

=> hash2(11) = 3 – (2)

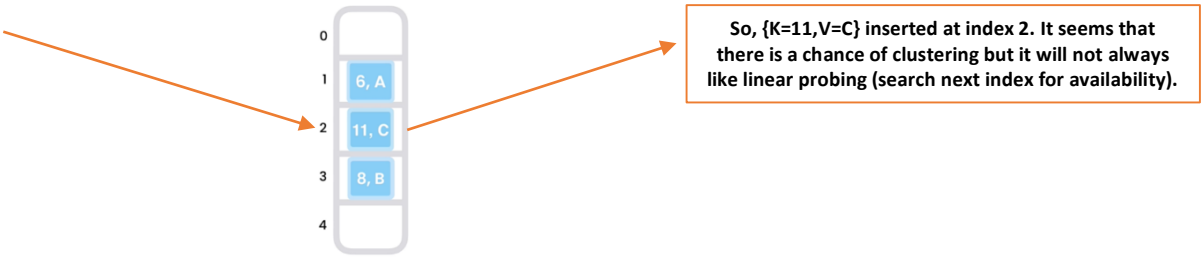
=> hash2(11) = 1 [using no. 2 formula]

for index finding we will use the second fromula of double hashing.

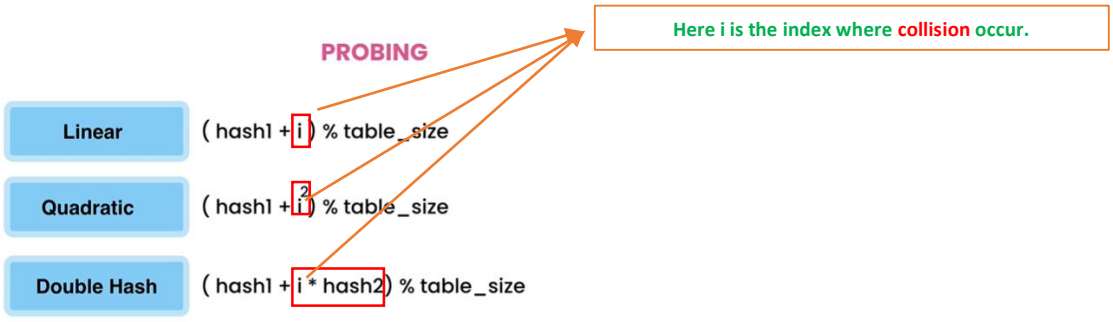
(hash1(11)+i*hash2(11)) % table_size

= (1+(1*1)) % 5

= 2



Probing Summary of video 12, 13 , 14:-



V-(15)-Build a HashTable-(Popular Interview questions):-

```
// HashTable
// put(k, v)
// get(k): v
// remove(k)
// k: int
// v: string
// Collisions: chaining
```

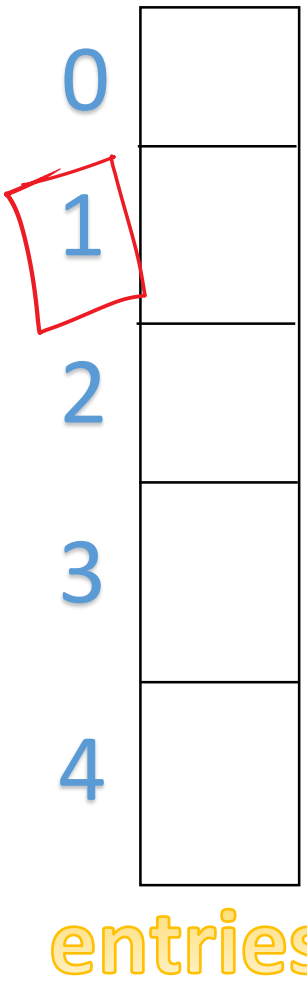
V-(16)-Build a HashTable-(put method):-

```
import java.util.LinkedList;

public class HashTable {
    private class Entry{
        // Entry object will be added in the specified index's LinkedList
        private int key;
        private String value;
        public Entry(int key, String value) {
            this.key = key;
            this.value = value;
        }
    }
    private LinkedList<Entry>[] entries = new LinkedList[5];

public void put(int key,String value){
        var index = hash(key);//get the index
        if(entries[index]==null){// if no entries happend before in that
//specified index
            entries[index]= new LinkedList<>();// make new LinkedList there
        }
        var bucket = entries[index];// as this is use many times (for refactor)
        for(var entry:bucket){// This loop is only for updating value if same
//key found
            if(entry.key==key){
                entry.value=value;
                return;
            }
        }
        // below 2 lines are for always entries with new keys to be added at
//the end of the list (list at the specified index)
        var entry = new Entry(key, value);
        bucket.addLast(entry);
    }
```

```
    private int hash(int key){
        return Math.abs(key% entries.length);// it will
//return positive value
    }
}
```



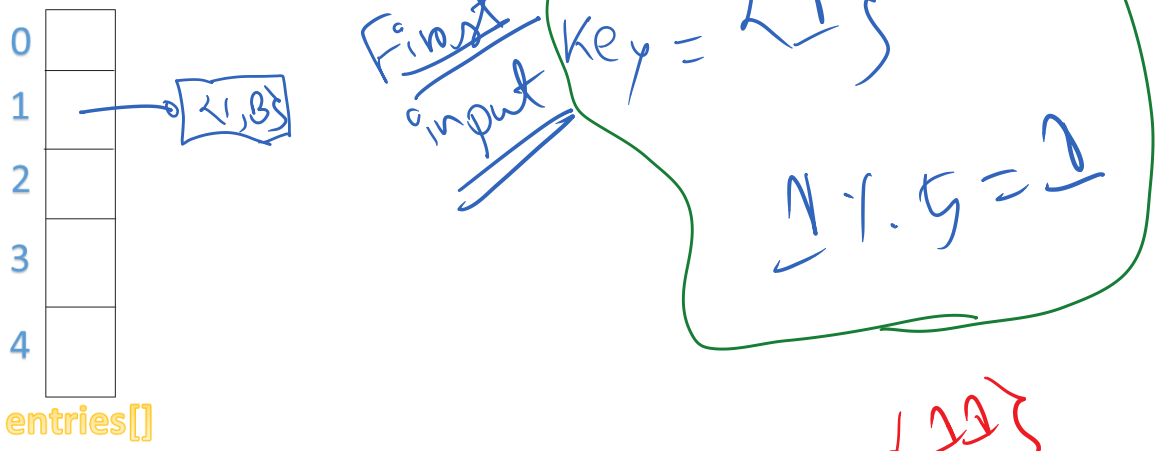
Put the values

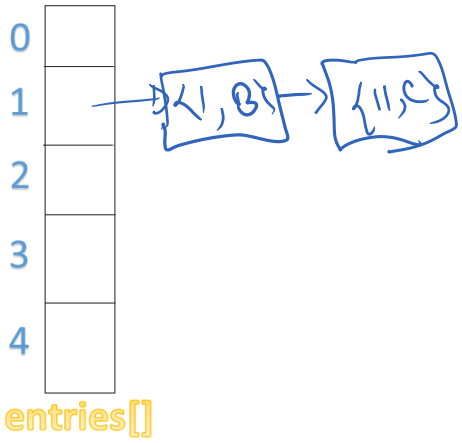
1. {K,V}={1,"B"}

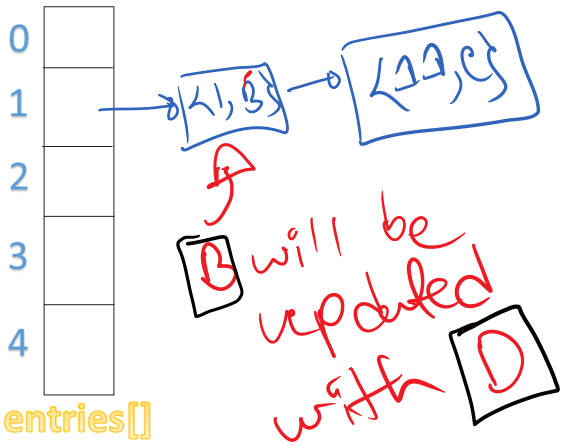
2.{K,V}={11,"C"}

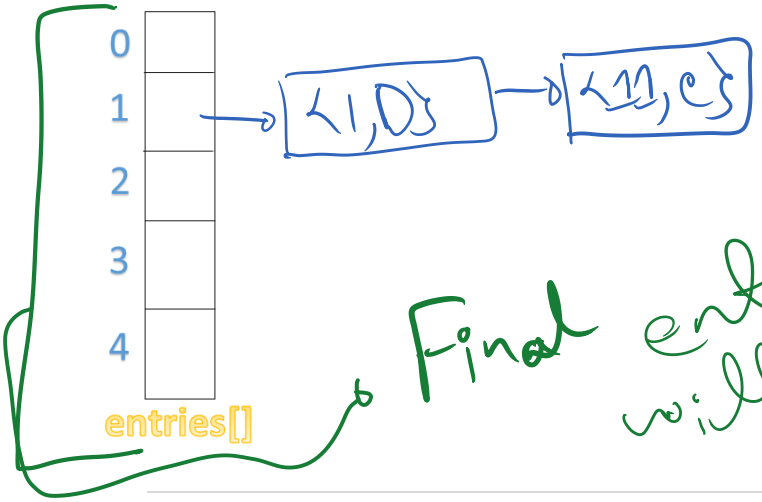
3.{K,V}={1,"D"}

For simulation see the next page.


0
1
2
3
4
entries[]
{1,B}
First input
key = {1}
1 % 5 = 1


0
1
2
3
4
entries[]
{1,B}
{11,C}
2nd input
key {11}
11 % 5 = 1

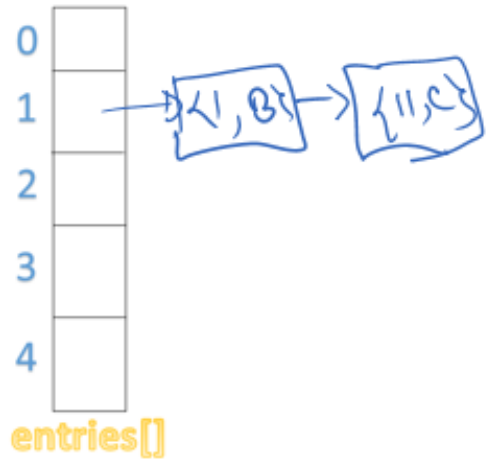

0
1
2
3
4
entries[]
{1,B}
{11,C}
D will be updated with D.
3rd input
key {1}
same key found so we will update the value in 1 no key.


0
1
2
3
4
entries[]
{1,D}
{11,C}
Final entries array will look like this

V-(17)-Build a HashTable-(get method):-

```
public String get(int key){
var index = hash(key);//Find the specific index for the
given key where data may be stored
var bucket = entries[index];// easy to realise when we
//renamed it bucket (also in put)
if(bucket!=null){//if no Linkedlist is created in the
//specific index then we don't need to iterate there
    for (var entry:bucket){
        if(entry.key==key)
            return entry.value;
    }
}
return null;
}
```

[N.B- First we have to find the index where keys maybe found in a LinkedList (in the specific index)]



Suppose we have to to find the value of a key{11}. So , we have to find the index where key may be stored in a linkedlist. So, we found the index using hash method and then iterate the linkedlist to find the given key if found then return the value of that key.

V-(18)-Build a HashTable-(remove method):-

```
public void remove(int key){
    var index = hash(key);//get the index
    var bucket = entries[index];//renamed as bucket so we can iterate
and remove the key value pair
    if(bucket == null)
        throw new IllegalStateException();
    for(var entry: bucket){
        if(entry.key == key){
            bucket.remove(entry);
        }
    }
    throw new IllegalStateException();// If key is not found anywhere
}
```

V-(19)-Build a HashTable-(Refactoring):-

```
import java.util.LinkedList;

public class HashTable {
    private class Entry{
        // Entry object will be added in the specified index's
LinkedList
        private int key;
        private String value;
        public Entry(int key, String value) {
            this.key = key;
            this.value = value;
        }
    }
    private LinkedList<Entry>[] entries = new LinkedList[5];
    public void put(int key,String value){
//         var entry = getEntry(key);
//         if(entry!=null){
//             entry.value = value;//updating the value if update
needed
//             return;
//         }
//         // below 2 lines will check if bucket need to create or
not
//         // if bucket needs to create it will be created
//         // then it will add the entry by calling constructor
//         getOrCreateBucket(key).add(new Entry(key, value));

        var index = hash(key);//get the index
        if(entries[index]==null){// if no entries happened before
in that specified index
            entries[index]= new LinkedList<>();// make new
LinkedList there
        }
        var bucket = entries[index];// as this is use many times
(for refactor)
        for(var entry:bucket){// This loop is only for updating
value if same key found
            if(entry.key==key){
                entry.value=value;
                return;
            }
        }
        // below line are for always entries with new keys to be
added at the end of the list (list at the specified index)
        bucket.addLast(new Entry(key, value));

    }
```

```
public String get(int key){
        // This below 2 line is very simple
        // check the entry found or not.
        // if found , then return the value of the entry ,
otherwise return null.
        var entry = getEntry(key);
        return (entry == null) ? null : entry.value;
    /*
    var index = hash(key);//Find the specific index for the given
key where data may be stored
    var bucket = entries[index];// easy to realize when we
renamed it bucket (also in put)
    if(bucket!=null){//if no Linkedlist is created in the
specific index then we don't need to iterate there
        for (var entry:bucket){
            if(entry.key==key)
                return entry.value;
        }
    }
    return null;
    */
    }
    private int hash(int key){
        return Math.abs(key% entries.length);// it will return
positive value
    }
    public void remove(int key){
        // below 3 lines logic is very simple
        // 1. find the entry,
        // 2. return null if entry not found
        // 3. but if found , find the bucket where the entry
exists, then remove the entry from the bucket.
        var entry = getEntry(key);
        if(entry == null)
            throw new IllegalStateException();
        getBucket(key).remove();
        /*
        // as we refactor and make our code simple , we don't
have to write code like below
        var index = hash(key);//get the index
        var bucket = entries[index];//renamed as bucket so we can
iterate and remove the key value pair
        if(bucket == null)
            throw new IllegalStateException();
        for(var entry: bucket){
            if(entry.key == key){
                bucket.remove(entry);
                return;
            }
        }
        throw new IllegalStateException();// If key is not found
anywhere
        */
```

```
    }
    private LinkedList<Entry> getOrCreateBucket(int key){
        // find the index using hash key
        // if no linkedlist is created in the index then create a
linkedlist and return.
        // otherwise it just return the linkedlist that created
before.
        var index = hash(key);
        var bucket = entries[index];
        if(bucket==null)
            entries[index] = new LinkedList<>();

        return bucket;
    }
    private LinkedList<Entry> getBucket(int key){
        /*var index = hash(key);// storing the index
        var bucket = entries[index];
        return bucket;
         */
        // for upper logic below one line is enough
        return entries[hash(key)];
        //method return type is LinkedList<Entry> cause in the
index data stored in linkedlist and class type is Entry.
    }
    private Entry getEntry(int key){
        /*
        var index = hash(key);// storing the index
        var bucket = entries[index];// easier to understand
        // as we developed getBucket method we do not have to
write code like this
        */
        var bucket = getBucket(key);//find the linkedlist where
key,value pair is stored.
        if(bucket !=null){// if bucket is not null then we have
to iterate through the bucket (list) , if found as same key then
return the entry
            for(var entry:bucket){
                if (entry.key == key)
                    return entry;
            }
        }
        return null;// if no such entry with the give key found,
then only return null
    }
}
```

Mosh Exercises:-

Ex-1)

1- Find the most repeated element in an array of integers. What is the time complexity of this method? (A variation of this exercise is finding the most repeated word in a sentence. The algorithm is the same. Here we use an array of numbers for simplicity.)

```
Input: [1, 2, 2, 3, 3, 3, 4]

Output: 3
```

Ans:-

```
// O(n)

  public int mostFrequent(int[] numbers) {
    // To find the most frequent item in an array, we have to count the
    // number of times each item has been repeated. We can use a hash
    // table to store the items and their frequencies.
    Map<Integer, Integer> map = new HashMap<>();
    for (var number : numbers) {
      var count = map.getOrDefault(number, 0);
      map.put(number, count + 1);
    }

    // Once we've populated our hash table, we need to iterate over all
    // key/value pairs and find the one with the highest frequency.
    int max = -1;
    int result = numbers[0];
    for (var item : map.entrySet()) {
      if (item.getValue() > max) {
        max = item.getValue();
        result = item.getKey();
      }
    }

    // Runtime complexity of this method is O(n) because we have to
    // iterate the entire array to populate our hash table.

    return result;
  }
```

Ex-2)

2- Given an array of integers, count the number of **unique** pairs of integers that have difference k.

```
Input: [1, 7, 5, 9, 2, 12, 3] K=2

Output: 4
```

We have four pairs with difference 2: (1, 3), (3, 5), (5, 7), (7, 9). Note that we only want the number of these pairs, not the pairs themselves.

Answer:-

```
// O(n)
public static int countPairsWithDiff(int[] numbers, int difference) {
    // For a given number (a) and difference (diff), number (b) can be:
    //
    // b = a + diff
    // b = a - diff
    //
    // We can iterate over our array of numbers, and for each number,
    // check to see if we have (current + diff) or (current - diff).
    // But looking up items in an array is an O(n) operation. With this
    // algorithm, we need two nested loops (one to pick a,
    // and the other to find b). This will be an O(n^2) operation.
    //
    // We can optimize this by using a set. Sets are like hash tables
    // but they only store keys. We can look up a number in constant time.
    // No need to iterate the array to find it.

    // So, we start by adding all the numbers to a set for quick look up.
    Set<Integer> set = new HashSet<>();
    for (var number : numbers)
        set.add(number);

    // Now, we iterate over the array of numbers one more time,
    // and for each number check to see if we have (a + diff) or
    // (a - diff) in our set.
    //
    // Once we're done, we should remove this number from our set
    // so we don't double count it.
    var count = 0;
```

```
    for (var number : numbers) {
        if (set.contains(number + difference))
            count++;
        if (set.contains(number - difference))
            count++;
        set.remove(number);
    }

    // Time complexity of this method is O(n).

    return count;
}
```

Ex-3)

Given an array of integers, return **indices** of the two numbers such that they add up to a specific target.

```
Input: [2, 7, 11, 15] - target = 9
Output: [0, 1] (because 2 + 7 = 9)
```

Assume that each input has **exactly** one solution, and you may not use
the *same* element twice.

Answer:-

```
// O(n)
public static int[] twoSum(int[] numbers, int target) {
    // This problem is a variation of the previous problem
    // (countPairsWithDiff).
    //
    // If a + b = target, then b = target - a.
    //
    // So we iterate our array, and pick (a). Then,
    // we check to see if we have (b) in our array.
    // Similar to the last problem, this would be an O(n^2)
    // operation, because we'll need two nested loops for
    // looking up (b).
    //
    // We can optimize this by using a hash table. In this
    // hash table, we store numbers and their indexes.
    //
    // There is no need to store all the numbers in the hash table
    // first. If we find two numbers that add up to the target,
    // we simply return their indexes.

    Map<Integer, Integer> map = new HashMap<>();
```

```
for (int i = 0; i < numbers.length; i++) {
        int complement = target - numbers[i];
        if (map.containsKey(complement)) {
            return new int[] { map.get(complement), i };
        }
        map.put(numbers[i], i);
    }

    // Time complexity of this method is O(n) because we need to iterate
    // the array only once.

    return null;
}
```

Ex-4)

4- Build a hash table from scratch. Use linear probing strategy for handling collisions. Implement the following operations:

- put(int, String)
- get(int)
- remove(int)
- size()

Answer:-

```
import java.util.Arrays;

public class HashMap {

    private class Entry {
        private int key;
        private String value;

        public Entry(int key, String value) {
            this.key = key;
            this.value = value;
        }

        @Override
        public String toString() {
            return value;
        }
    }

    private Entry[] entries = new Entry[5];
```

```
private int count;

public void put(int key, String value) {
    var entry = getEntry(key);
    if (entry != null) {
        entry.value = value;
        return;
    }

    if (isFull())
        throw new IllegalStateException();

    entries[getIndex(key)] = new Entry(key, value);
    count++;
}

public String get(int key) {
    var entry = getEntry(key);
    return entry != null ? entry.value : null;
}

public void remove(int key) {
    var index = getIndex(key);
    if (index == -1 || entries[index] == null)
        return;

    entries[index] = null;
    count--;
}

public int size() {
    return count;
}

private Entry getEntry(int key) {
    var index = getIndex(key);
    return index >= 0 ? entries[index] : null;
}

private int getIndex(int key) {
    int steps = 0;

    // Linear probing algorithm: we keep looking until we find an empty
    // slot or a slot with the same key.

    // We use this loop conditional to prevent an infinite loop that
    // will happen if the array is full and we keep probing with no
    // success. So, the number of steps (or probing attempts) should
    // be less than the size of our table.
    while (steps < entries.length) {
```

```
            int index = index(key, steps++);
            var entry = entries[index];
            if (entry == null || entry.key == key)
                return index;
        }

        // This will happen if we looked at every slot in the array
        // and couldn't find a place for this key. That basically means
        // the table is full.
        return -1;
    }

    private boolean isFull() {
        return count == entries.length;
    }

    private int index(int key, int i) {
        return (hash(key) + i) % entries.length;
    }

    private int hash(int key) {
        return key % entries.length;
    }

    @Override
    public String toString() {
        return Arrays.toString(entries);
    }
}
```

Summary:-