Hashmap Implementation

Check if given element exists in Q queries

Given an array of size N and Q queries. In each query, an element is given. We have to check whether that element exists or not in the given array.

Example

A [ ] = { `2, 4, 11, 15 , 6, 8, 14, 9` }

`4 Queries`
`K = 4` (return true)
`K = 10` (return false)
`K = 17` (return false)
`K = 14` (return true)

:::warning
Please take some time to think about the solution approach on your own before reading further.....
:::

Brute Force Approach

For every query, loop through the given array to check the presence.

Time Complexity - **O(N * Q)**
Space Complexity - **O(1)**

Observation

We can create an array to mark the presence of an element against that particular index.

A [ ] = { `2, 4, 11, 15 , 6, 8, 14, 9` }

For example we can mark presence of
2 at index 2
4 at index 4 and so on....

To execute that, we'll need to have indices till 15(max of Array).
The array size needed is 16.

Let's call that array as - DAT (Direct Access Table)
int dat[16] = {0}; //initally assuming an element is not present

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Let's mark the presence.

```
for(int i = 0; i < N; i++) {
    dat[A[i]] = 1;
}
```

Below is how that array looks like -

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	0	1	0	1	0	1	1	0	1	0	0	1	1

Advantage of using DAT

1. Time Complexity of Insertion - `O(1)`
2. Time Complexity of Deletion - `O(1)`
3. Time Complexity of Search - `O(1)`

Issues with such a representation

1. Wastage of Space

- Say array is `A[] = {23, 60, 37, 90}` ; now just to store presence of 4 elements, we'll have to construct an array of `size 91` .

2. Inability to create big Arrays

- If values in array are as big as 10^{15}, then we will not be able to create this big array. At max array size possible is 10^6(around)

3. Storing values other than positive Integers

- We'll have to make some adjustments to store negative numbers or characters. (It'll be possible but needs some work-around)

Overcome Issues while retaining Advantages

Let's say we have restriction of creating only array of size 10.

Given Array -
A [ ] = { `21, 42, 37, 45 , 99, 30` }

How can we do so ?

In array of size 10, we'll have indices from 0 to 9. How can we map all the values within this range ?

Basically, we can take a mod with 10.

21 % 10 = 1 (presence of 21 can be marked at index 1)

42 % 10 = 2 (presence of 42 can be marked at index 2)

37 % 10 = 7 (presence of 37 can be marked at index 7)

45 % 10 = 5 (presence of 45 can be marked at index 5)

99 % 10 = 9 (presence of 99 can be marked at index 9)

30 % 10 = 0 (presence of 30 can be marked at index 0)

0	1	2	3	4	5	6	7	8	9
30	21	42	0	0	45	0	37	0	99

What Have We Done ?

- We have basically done Hashing. Hashing is a process where we pass our data through the Hash Funtion which gives us the hash value(index) to map our data to.
- In this case, the hash function used is **MOD**. This is the simplest hash function. Usually, more complex hash functions are used.
- The DAT that we created is known as **Hash Table** in terms of Hashing.

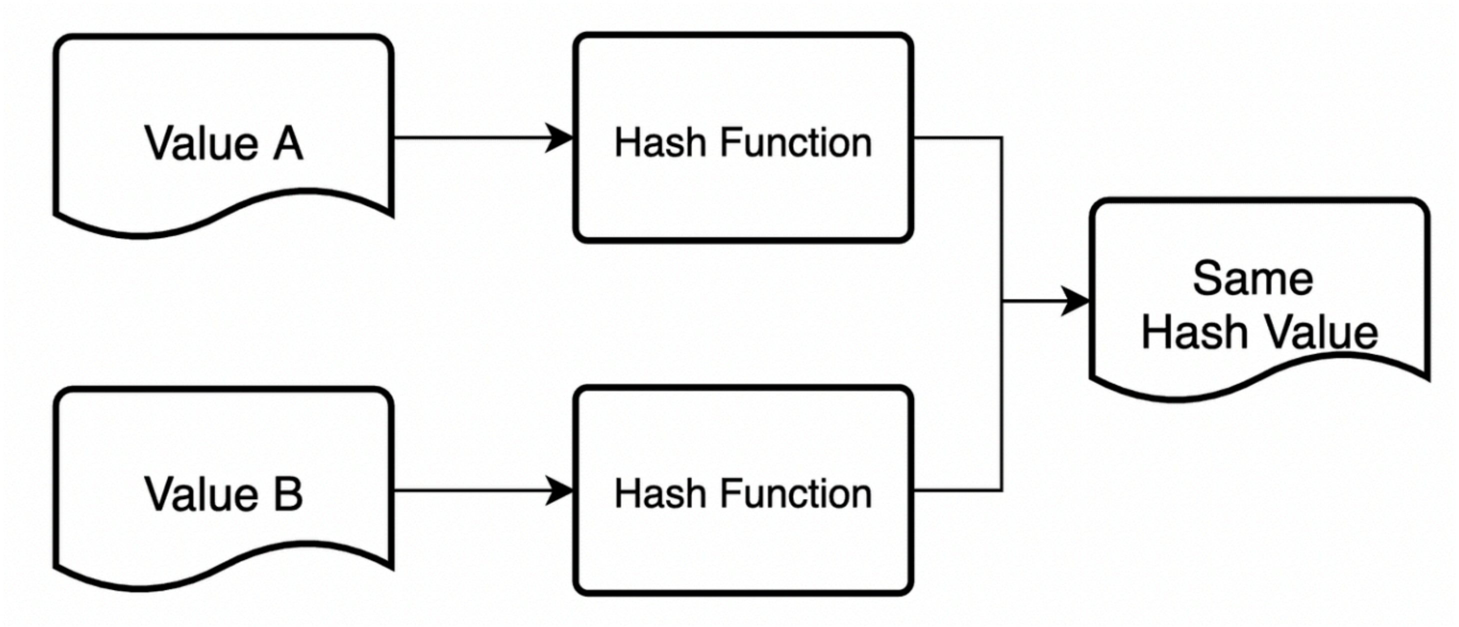
Issue with Hashing ?

COLLISION!

Say given array is as follows -

A [ ] = {21, 42, 37, 45, 77, 99, 31}

Here, 21 & 31 will map to the same index => 1
37 & 77 map to same index => 7



Can we completely avoid collision ?

`Not Really!`

No matter how good a hash function is, we can't avoid collision!

Why ?

We are trying to map big values to a smaller range, collisions are bound to happen.

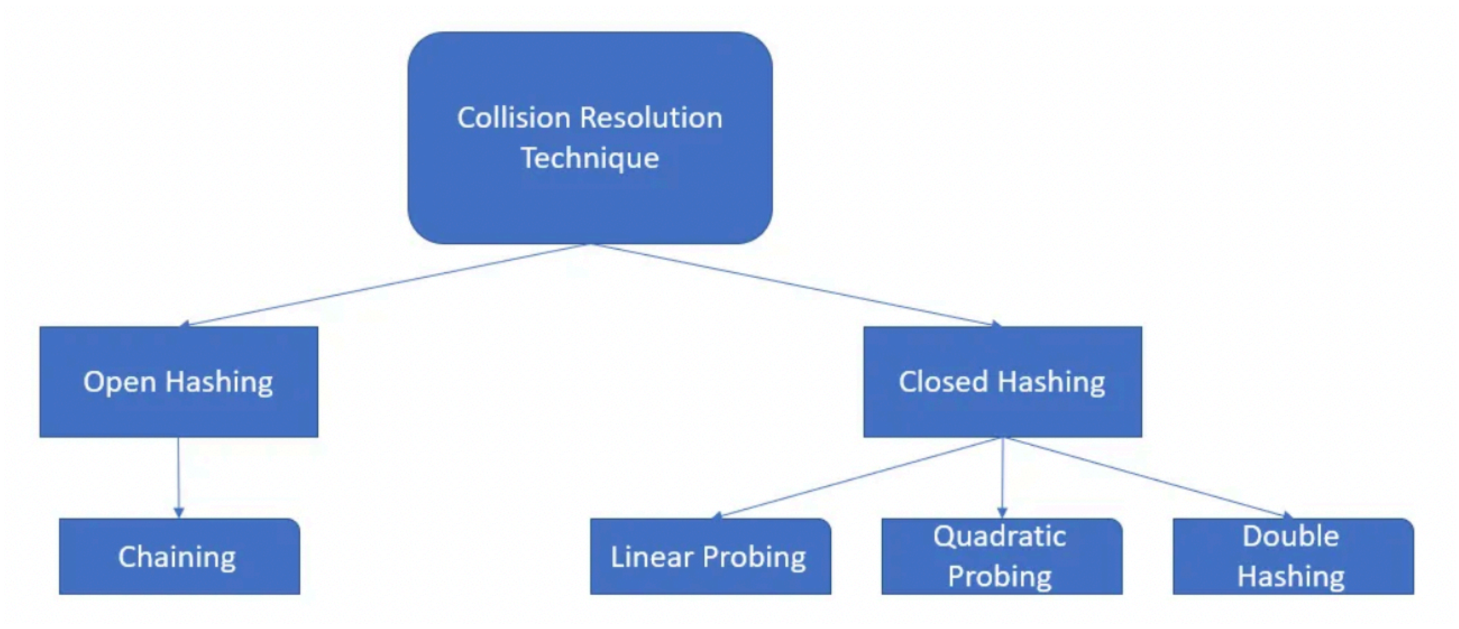
Moreover, this can be explained using `Pigeon Hole Principle!`

Example -

Say we have 11 pigeons and we have only 8 holes to keep them. Now, provided holes are less, atleast 2 pigeons need to fit in a single hole.

But, we can find some resolutions to collision.

Collision Resolution Techniques



> From Interview Perspective, Open Hashing is Important hence, we'll dive into that.

Chaining

Let's take the above problem where collision happened!

A [ ] = { `21, 42, 37, 45, 77, 99, 31` }

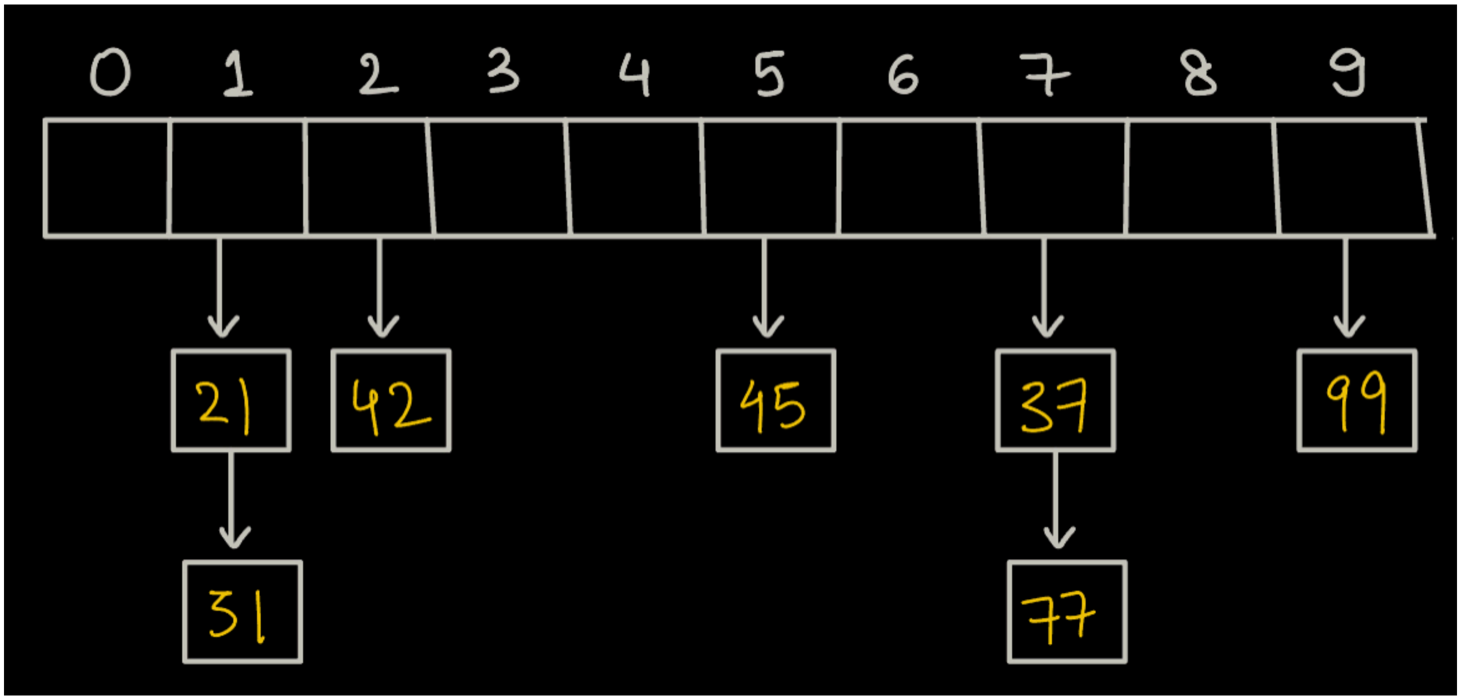
Here, 21 & 31 will map to the same index => 1
37 & 77 map to same index => 7

How can we resolve Collision here?

We can somehow store both 21 & 31 at the same index.

Basically we can have a linked list at every index.
i.e, Array of Linked List

Every index shall have head node of Linked List.



The above method is known as Chaining.

- **Chaining** is a technique used in data structures, particularly hash tables, to resolve collisions. When multiple items hash to the same index, chaining stores them in a linked list or another data structure at that index.

What will be the Time Complexity of Insertion ?

- First we will pass the given element to Hash Function, which will return an index. Now, we will simply add that element to the Linked List at that index.
- If we insert at **tail** => `O(N)`
- If we insert at **head** => `O(1)`
  Since order of Insertion doesn't matter to us, so we can **simply insert at head**.

What will be the Time Complexity of Deletion and Searching ?

- Time Complexity on average is always less than λ. λ is known as lamda.
- Time Complexity in worst case is still O(N)

What is lamda

There is a lamba(λ) function which is nothing but a ratio of (number of elements inserted / size of the array).

Example:

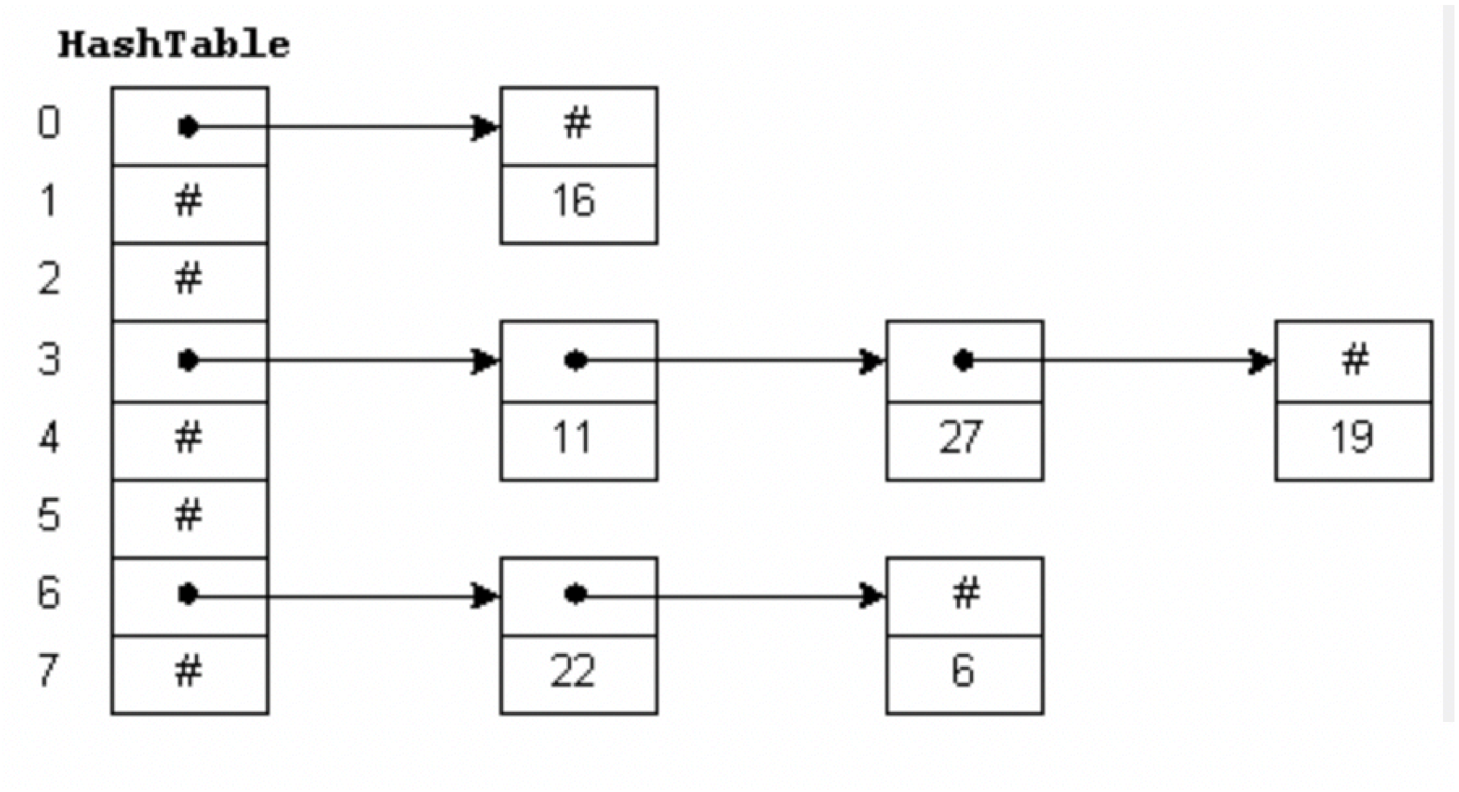


Table size(Array size) = 8
Inserted Elements = 6

λ = $\frac{6}{8}$ = 0.75

Let's assume the predefined threshold is 0.7. The load factor is exceeding this value, so we will need to rehash the table.

Rehashing:

- Create a new hash table with double the size of the original hash table. In this case, the new size will be
- 8×2=16
- Redistribute the existing elements to their new positions in the larger hash table using a new hash function.
- The load factor is now recalculated for the new hash table:
-

λ = $\frac{6}{16} = 0.375$ (within the threshold of 0.7)

Code Implementation

Declaring the HashMap Class

Let's go through the code implementation of a hashmap:

- The HashMap class is defined with generic types `K` and `V` for keys and values.
- The inner class `HMNode` represents a node containing a key-value pair.
- `buckets` is an array of ArrayLists to store key-value pairs.
- `size` keeps track of the number of key-value pairs in the hashmap.
- The `initbuckets()` method initializes the array of buckets with a default size of 4.

```
import java.util.ArrayList;

class HashMap < K, V > {

        private class HMNode {
            K key;
            V value;

            public HMNode(K key, V value) {
                this.key = key;
                this.value = value;
            }
        }

        private ArrayList < HMNode > [] buckets;
        private int size; // number of key-value pairs

        public HashMap() {
            initbuckets();
            size = 0;
        }

        private void initbuckets() {
            buckets = new ArrayList[4];
            for (int i = 0; i < 4; i++) {
                buckets[i] = new ArrayList < > ();
            }
        }
```

Put Method

- The `put` method adds a key-value pair to the hashmap.
- It calculates the bucket index (`bi`) using the `hash` method and finds the data index within the bucket using `getIndexWithinBucket` .
- If the key is found in the bucket, it updates the value. Otherwise, it inserts a new node.
- After inserting, it checks the load factor (`lambda`) and triggers rehashing if the load factor exceeds 2.0.

```java
public void put(K key, V value) {
    int bi = hash(key);
    int di = getIndexWithinBucket(key, bi);

    if (di != -1) {
        // Key found, update the value
        buckets[bi].get(di).value = value;
    } else {
        // Key not found, insert new key-value pair
        HMNode newNode = new HMNode(key, value);
        buckets[bi].add(newNode);
        size++;

        // Check for rehashing
        double lambda = size * 1.0 / buckets.length;
        if (lambda > 2.0) {
            rehash();
        }
    }
}
```

Hash Method

- The `hash` method calculates the bucket index using the hash code of the key and takes the modulus to ensure it stays within the array size.

```java
  private int hash(K key) {
    int hc = key.hashCode();
    int bi = Math.abs(hc) % buckets.length;
    return bi;
}
```

Get Index within Bucket

- The `getIndexWithinBucket` method searches for the data index (`di`) of a key within a specific bucket. It returns -1 if the key is not found

```
private int getIndexWithinBucket(K key, int bi) {
    int di = 0;
    for (HMNode node: buckets[bi]) {
        if (node.key.equals(key)) {
            return di; // Key found
        }
        di++;
    }
    return -1; // Key not found
}
```

Rehash Method

- The `rehash` method is called when the load factor exceeds 2.0.
- It creates a new array of buckets, initializes the size to 0, and iterates through the old buckets, reinserting each key-value pair into the new array.
-

```
private void rehash() {
    ArrayList < HMNode > [] oldBuckets = buckets;
    initbuckets();
    size = 0;

    for (ArrayList < HMNode > bucket: oldBuckets) {
        for (HMNode node: bucket) {
            put(node.key, node.value);
        }
    }
}
```

Get Method

- The `get` method retrieves the value associated with a given key. It calculates the bucket index and searches within the bucket to find the key.

```
public V get(K key) {
    int bi = hash(key);
    int di = getIndexWithinBucket(key, bi);

    if (di != -1) {
        return buckets[bi].get(di).value;
    } else {
        return null;
    }
}
```

Contains Key Method

- The `containsKey` method checks if a given key exists in the hashmap by calculating the bucket index and checking the data index within the bucket.

```
public boolean containsKey(K key) {
    int bi = hash(key);
    int di = getIndexWithinBucket(key, bi);

    return di != -1;
}
```

Remove Method

- The `remove` method removes a key-value pair from the hashmap. If the key is found, it returns the value; otherwise, it returns null

```
public V remove(K key) {
    int bi = hash(key);
    int di = getIndexWithinBucket(key, bi);

    if (di != -1) {
        // Key found, remove and return value
        size--;
        return buckets[bi].remove(di).value;
    } else {
        return null; // Key not found
    }
}
```

Size Method

The `size` method returns the total number of key-value pairs in the hashmap.

```
public int size() {
    return size;
}
```

Key Set Method

- The `keyset` method returns an ArrayList containing all the keys in the hashmap by iterating through the buckets and nodes.

```
public ArrayList < K > keyset() {
    ArrayList < K > keys = new ArrayList < > ();
    for (ArrayList < HMNode > bucket: buckets) {
        for (HMNode node: bucket) {
            keys.add(node.key);
        }
    }
    return keys;
}
}
```

Question

What is the time complexity of the brute-force approach for checking the existence of an element in the array for Q queries?

Choices

- [ ] O(N)
- [ ] O(Q)
- [✓ O(N * Q)]
- [ ] O(1)

Question

What advantage does the Direct Access Table (DAT) provide in terms of time complexity for insertion, deletion, and search operations?

Choices

- [x] O(1) for all operations
- [ ] O(N) for all operations
- [ ] O(1) for insertion and deletion, O(N) for search
- [ ] O(N) for insertion and deletion, O(1) for search

Question

What is the purpose of the load factor (lambda) in a hashmap?

Choices

- [ ] It represents the number of elements in the hashmap.
- [ ] It is used to calculate the hash code of a key.
- [x] It determines when to trigger rehashing.
- [ ] It controls the size of the hashmap.

Question

What does the rehashing process involve in a hashmap?

Choices

- [ ] Reducing the size of the hashmap
- [x] Creating a new hash table with double the size and redistributing elements
- [ ] Deleting all elements from the hashmap
- [ ] Removing collision resolution techniques