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# CS2040 Data Structures and Algorithms

## Lecture Note #7

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### Map ADT – HashTable

*For efficient look-up in a table*

# Objectives

1

- To know Map ADT and one efficient implementation – hashing/hashtable

2

- To understand how **hashing** is used to accelerate table lookup

3

- To study the issue of **collision** and techniques to resolve it

# Outline

1. Map ADT and Hashing
2. Direct Addressing Table
3. Hash Table
4. Hash Functions
  - Good/bad/perfect/uniform hash function
5. Collision Resolution
  - Separate Chaining
  - Linear Probing
  - Quadratic Probing
  - Double Hashing
  - Performance of hash table operations
6. Set ADT
7. Summary
8. Java HashMap Class

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# **1 Map ADT and Hashing**

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An ADT to map values to keys

# 1. Map ADT and Hashing

## ■ Map ADT

- An abstract data type that contains a collection of  $\langle \text{key}, \text{value} \rangle$  pairs/mappings
- It associates a **key** to a **value** in a one-to-one or many-to-one relation
- There cannot be duplicate **keys** in the map
- There are 3 basic operations
  - **Retrieval** – retrieve the **value** using the given **key**
  - **Insertion** – insert/replace a **value** using the given **key**
  - **Deletion** – delete the  $\langle \text{key}, \text{value} \rangle$  pair using the given **key**

# 1. Map ADT and Hashing

- **Hashing** which is performed via a **hash function** is one concrete way for Map ADT to map a key to its value.
- A hash table (or hash map) is a data structure that uses a hash function to efficiently map keys to values, for efficient search and retrieval.
- Widely used in many kinds of computer software, particularly for associative arrays, database indexing and caches.

# 1. Map ADT Operations

	<b>Sorted List</b> (Array impl. By sorting key)	Balanced BST	<b>HashTable</b>
<b>Insertion</b>	$O(n)$	$O(\log n)$	$O(1)$ avg
<b>Deletion</b>	$O(n)$	$O(\log n)$	$O(1)$ avg
<b>Retrieval</b>	$O(\log n)$	$O(\log n)$	$O(1)$ avg

**Note:** Balanced Binary Search Tree (bBST) will be covered in later lectures.

- Hence, hash table supports the Map ADT in constant time on average for the above operations. It has many applications.

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## **2 Direct Addressing Table**

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A simplified version of hash table



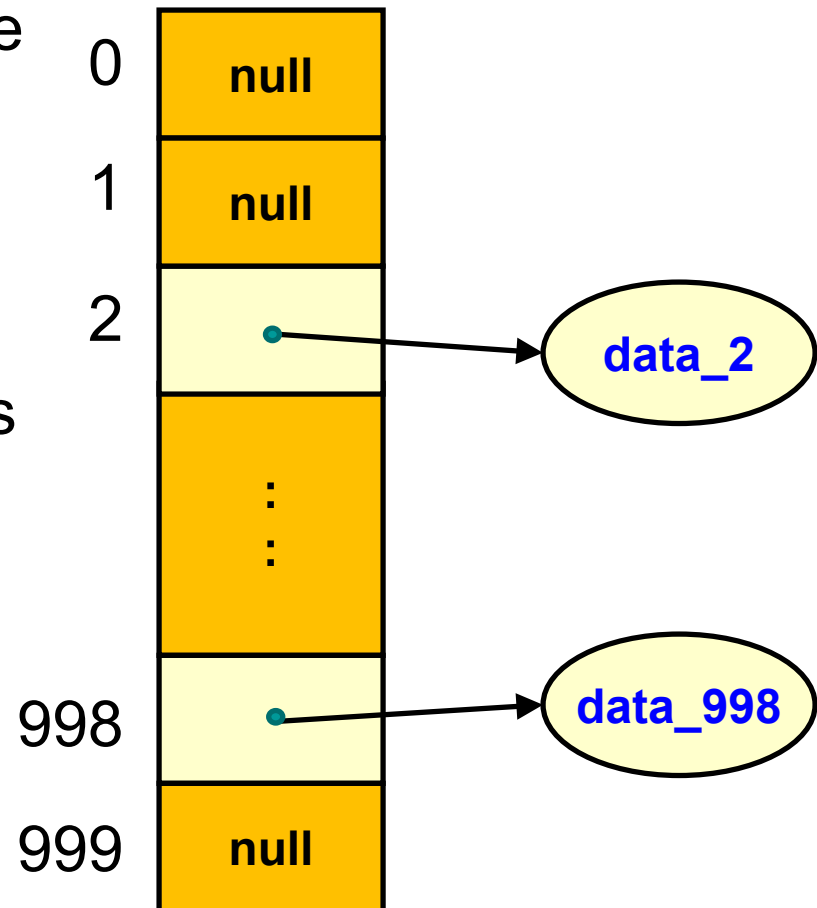
## 2 SBS Transit Problem

- Retrieval: **find**(*num*)
  - Find the bus route of bus service number *num*
- Insertion: **insert**(*num*, *data*)
  - Introduce a new bus service number *num*
- Deletion: **delete**(*num*)
  - Remove bus service number *num*

## 2 Direct Addressing Table

Assume that bus numbers are integers between 0 and 999, we can create an array of 1000 slots, each is a **reference** to an object which contains the details of the bus route (**one-to-one** mapping).

**Note:** You will want to store the key values, i.e. bus numbers, also.



## 2 Direct Addressing Table: Operations

**insert** (key, data)

$a[\text{key}] = \text{data}$       // where  $a[]$  is an array – the table

**delete** (key)

$a[\text{key}] = \text{null}$

**find** (key)

return  $a[\text{key}]$

## 2 Direct Addressing Table: Restrictions

- Keys must be **non-negative integer values**
  - What happens for key values 151A and NR10?
- Range of keys must be **small**
- Keys must be **dense**, i.e. not many gaps in the key values.
- How to overcome these restrictions?

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## 3 Hash Table

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Hash Table is a **generalization** of direct addressing table, to remove the latter's restrictions.

### 3 Origins of the term Hash

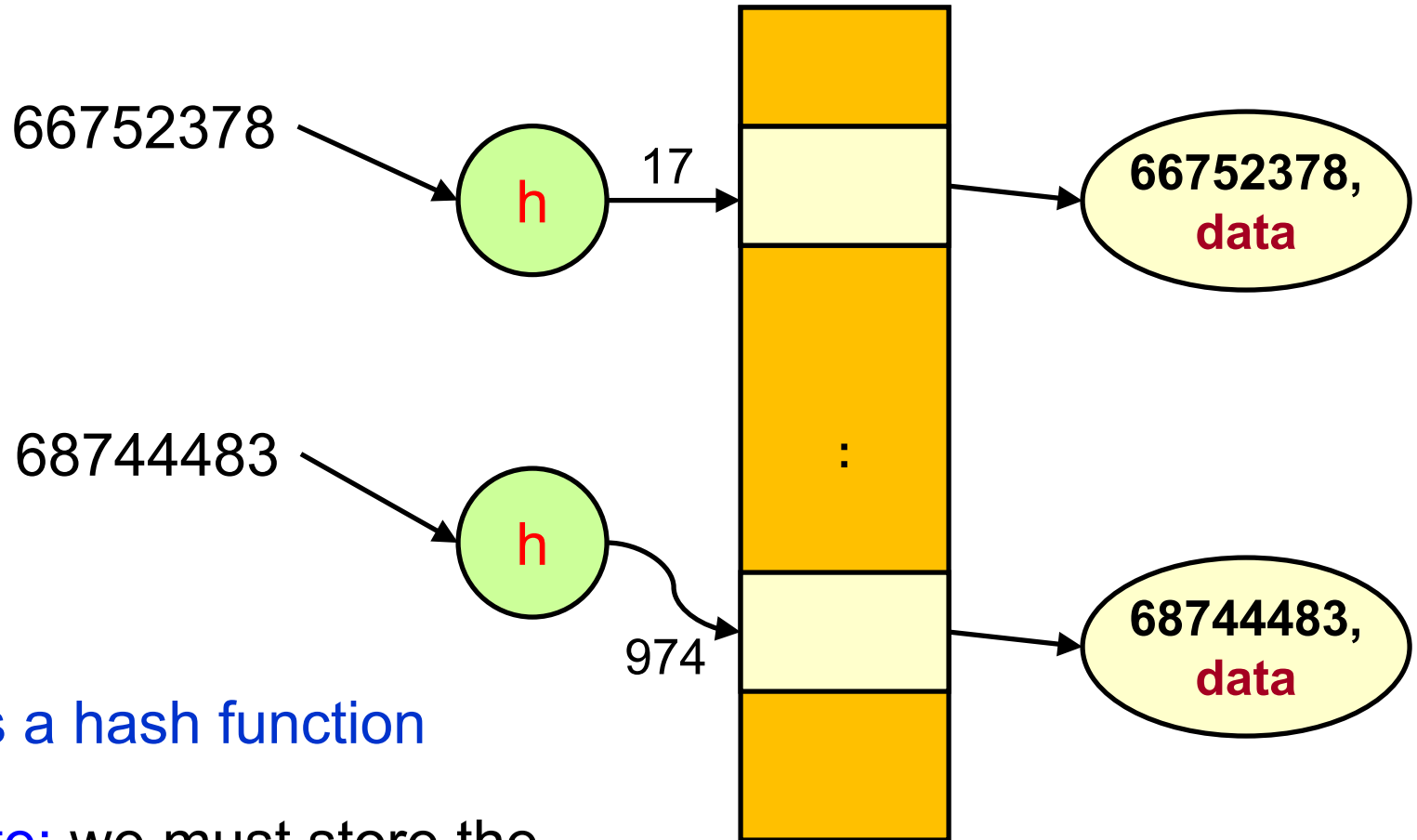
- The term "hash" comes by way of analogy with its standard meaning in the physical world, to "chop and mix".
- Indeed, typical hash functions, like the mod operation, "chop" the input domain into many sub-domains that get "mixed" into the output range.
- Donald Knuth notes that Hans Peter Luhn of IBM appears to have been the first to use the concept, in a memo dated January 1953, and that Robert Morris used the term in a survey paper in CACM which elevated the term from technical jargon to formal terminology.

## 3 Ideas

- Map **large** integers to **smaller** integers
- Map **non-integer** keys to **integers**

# HASHING

# 3 Hash Table



**h** is a hash function

**Note:** we must store the key values. **Why?**



### 3 Hash Table: Operations

**insert** (key, data)

$a[h(\text{key})] = \text{data}$  //  $h$  is a hash function and  $a[]$  is an array

**delete** (key)

$a[h(\text{key})] = \text{null}$

**find** (key)

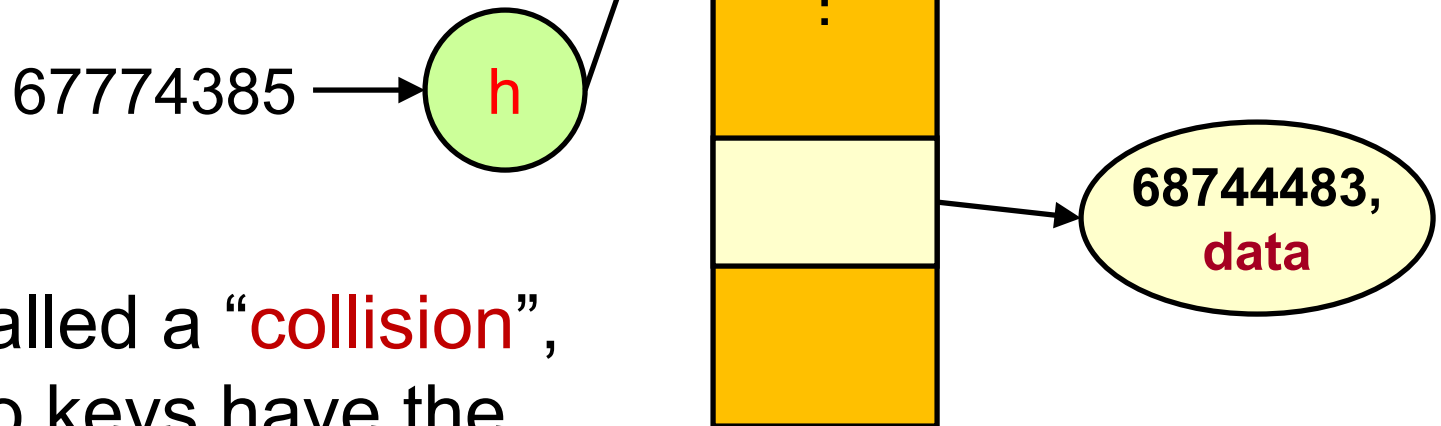
return  $a[h(\text{key})]$

However, this does **not** work for **all** cases!  
(Why?)

### 3 Hash Table: Collision

A hash function does **not** guarantee that two different keys go into **different slots**! It is usually a **many-to-one** mapping and not one-to-one.

**E.g.** 67774385 hashes to the same location of 66752378.



This is called a “**collision**”, when two keys have the same hash value.

### 3 Two Important Issues

- How to **hash**?
- How to **resolve collisions**?
- These are important issues that can affect the efficiency of hashing

# **4 Hash Functions**

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## 4 Criteria of **Good** Hash Functions

- Fast to compute
- Scatter keys **evenly** throughout the hash table
- Less collisions
- Need **less slots** (space)

## 4 Example of **Bad** Hash Function

- Select Digits — e.g. choose the 4<sup>th</sup> and 8<sup>th</sup> digits of a phone number
  - $\text{hash}(677\mathbf{5}437\mathbf{8}) = 58$
  - $\text{hash}(634\mathbf{9}782\mathbf{0}) = 90$
- What happen when you hash Singapore's house phone numbers by selecting the **first three digits**?

## 4 Perfect Hash Functions

- **Perfect hash function** is a **one-to-one** mapping between keys and hash values. So **no collision** occurs.
- Possible if **all keys** are known beforehand.
- **Applications:** compiler and interpreter search for reserved words; shell interpreter searches for built-in commands.
- **GNU gperf** is a freely available perfect hash function generator written in C++ that automatically constructs perfect functions (a C++ program) from a user supplied list of keywords.
- **Minimal perfect hash function:** The table size is the same as the number of keywords supplied.

## 4 Uniform Hash Functions

- Distributes keys **evenly** in the hash table
- Example
  - If  $k$  integers are **uniformly** distributed among **0** and  **$X-1$** , we can map the values to a hash table of size  **$m$**  ( $m < X$ ) using the hash function below

$$k \in [0, X)$$

$$\text{hash}(k) = \left\lfloor \frac{km}{X} \right\rfloor$$

$k$  is the key value

$[ ]$ : close interval

$( )$ : open interval

Hence,  $0 \leq k < X$

$\lfloor \rfloor$  is the **floor** function



## 4 Division method (**mod** operator)

- Map into a hash table of *m* slots.
- Use the **modulo** operator (**%** in Java) to map an integer to a value between 0 and *m*-1.
- *n mod m* = remainder of *n* divided by *m*, where *n* and *m* are positive integers.

$$\textit{hash}(k) = k \% m$$

The most popular method.

## 4 Multiplication method

1. Multiply by a constant real number  $\mathbf{A}$  between 0 and 1
2. Extract the fractional part
3. Multiply by  $m$ , the hash table size

$$hash(k) = \lfloor m(k\mathbf{A} - \lfloor k\mathbf{A} \rfloor) \rfloor$$

The reciprocal of the golden ratio

=  $(\sqrt{5} - 1)/2 = 0.618033$  seems to be a good choice for  $\mathbf{A}$  (recommended by Knuth).

## 4 How to pick $m$ ?

- The choice of  $m$  (or **hash table size**) is important. If  $m$  is power of two, say  $2^n$ , then key modulo of  $m$  is the same as extracting the last  $n$  bits of the key.
- If  $m$  is  $10^n$ , then our hash values is the last  $n$  digit of keys.
- Both are no good.
- **Rule of thumb:**
  - Pick a **prime number** close to a power of two to be  $m$ .

## 4 Hashing of strings (1/4)

- An example hash function for strings:

```
hash(s) {    // s is a string
    sum = 0
    for each character c in s {
        sum += c    // sum up the ASCII values of all characters
    }
    return sum % m    // m is the hash table size
}
```

## 4 Hashing of strings: Examples (2/4)

hash("Tan Ah Teck")

= ("T" + "a" + "n" + " " +  
"A" + "h" + " " +  
"T" + "e" + "c" + "k") % 11 // hash table size is 11

= (84 + 97 + 110 + 32 +  
65 + 104 + 32 +  
84 + 101 + 99 + 107) % 11

= 825 % 11

= 0

## 4 Hashing of strings: Examples (3/4)

- All 3 strings below have the same hash value!  
Why?
  - Lee Chin Tan
  - Chen Le Tian
  - Chan Tin Lee
- **Problem:** This hash function value does not depend on positions of characters! – Bad

## 4 Hashing of strings (4/4)

- A better hash function for strings is to “shift” the sum after each character, so that the positions of the characters affect the hash value.

**hash(s)**

sum = 0

**for each** character c in s {

sum = sum\*31 + c

}

**return** sum % m      // m is the hash table size

Java's String.hashCode() uses \*31 as well.

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# **5 Collision Resolution**

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## 5 Probability of Collision (1/2)

- **von Mises Paradox (The Birthday Paradox):**

“How many people must be in a room before the probability that some **share a birthday**, ignoring the year and leap days, becomes at least 50 percent?”

$Q(n)$  = Probability of **unique** birthday for  $n$  people

$$= \frac{365}{365} \times \frac{364}{365} \times \frac{363}{365} \times \frac{362}{365} \dots \frac{365 - n + 1}{365}$$

$P(n)$  = Probability of **collisions** (same birthday) for  $n$  people  
 $= 1 - Q(n)$

$$P(\mathbf{23}) = \mathbf{0.507}$$

Hence, you need only 23 people in the room!

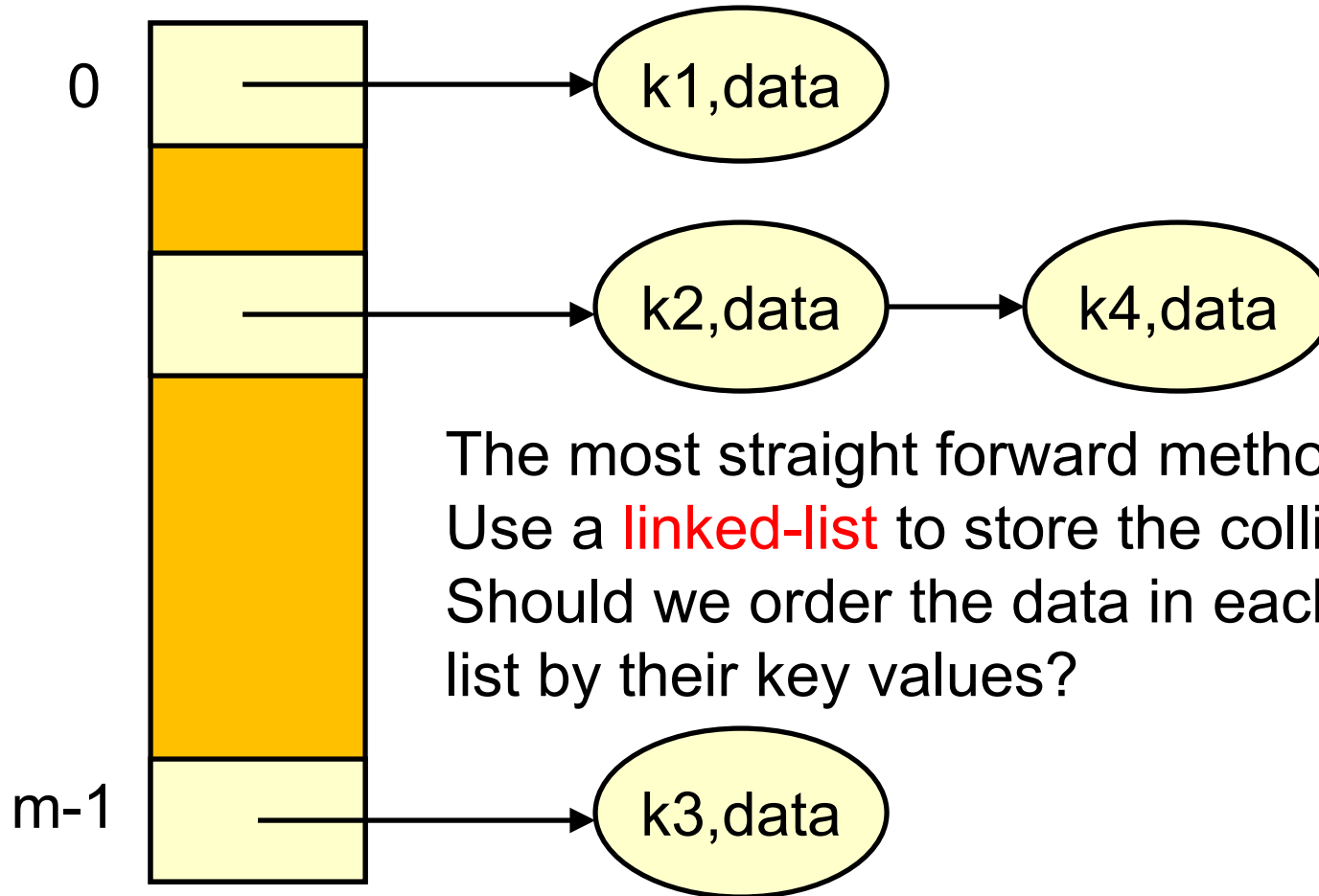
## 5 Probability of Collision (2/2)

- This means that if there are 23 people in a room, the probability that some people share a birthday is 50.7%!
- In the hashing context, if we insert 23 keys into a table with 365 slots, more than half of the time we will get collisions! Such a result is counter-intuitive to many.
- So, collision is very likely!

# 5 Collision Resolution Techniques

- Separate Chaining
- Open Addressing
  - Linear Probing + Modified Linear Probing
  - Quadratic Probing
  - Double Hashing

## 5.1 Separate Chaining



The most straight forward method.  
Use a **linked-list** to store the collided keys.  
Should we order the data in each linked list by their key values?

## 5.1 Hash operations

### insert (key, data)

Insert data into the list  $a[h(\text{key})]$

Takes worst case  $O(n)$  time, where  $n$  is length of the chain

### find (key)

Find key from the list  $a[h(\text{key})]$

Takes worst case  $O(n)$  time

### delete (key)

Delete data from the list  $a[h(\text{key})]$

Takes worst case  $O(n)$  time

## 5.1 Analysis: Performance of Hash Table

- $n$ : number of keys in the hash table
- $m$ : size of the hash tables – number of slots
- $\alpha$ : load factor

$$\alpha = n/m$$

a measure of **how full** the hash table is. If table size is the number of linked lists, then  $\alpha$  is the average length of the linked lists.

- Using a linked list for the chains also means separate chaining is not cache friendly

## 5.1 Reconstructing Hash Table

- To keep  $\alpha$  bounded, we may need to **reconstruct** the whole table when the load factor exceeds the bound.
- Whenever the load factor exceeds the bound, we need to **rehash** all keys into a **bigger** table (increase  $m$  to reduce  $\alpha$ ), say a prime close to double the table size  $m$ .

## 5.2 Linear Probing - Find

$$\text{hash}(k) = k \bmod 7$$

Here the table size  $m=7$

Note: 7 is a prime number.

0	14
1	21
2	1
3	35
4	18
5	
6	



## 5.2 Linear Probing: Find 35

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(35) = 0$$

0	14
1	21
2	1
3	35
4	18
5	
6	

Found 35, after 4 probes.

## 5.2 Linear Probing: Find 8

$\text{hash}(k) = k \bmod 7$

$\text{hash}(8) = 1$

0	14
1	21
2	1
3	35
4	18
5	
6	

8 NOT found.  
Need **5** probes!

## 5.2 Linear Probing - Insertion

$$\text{hash}(k) = k \bmod 7$$

0	
1	
2	
3	
4	
5	
6	

Start with an empty hash table

## 5.2 Linear Probing: Insert 18

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(18) = 18 \bmod 7 = 4$$

0	
1	
2	
3	
4	18
5	
6	

1. Find 18
2. If 18 not found insert at 1<sup>st</sup> empty slot
3. If 18 found update value associated with 18 if needed (there are no duplicate keys in the hash table !)

## 5.2 Linear Probing: Insert 14

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(18) = 18 \bmod 7 = 4$$

$$\text{hash}(14) = 14 \bmod 7 = 0$$

0	14
1	
2	
3	
4	18
5	
6	

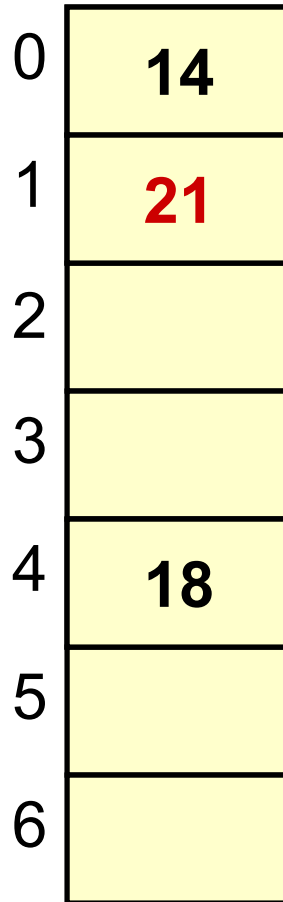
## 5.2 Linear Probing: Insert 21

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(18) = 18 \bmod 7 = 4$$

$$\text{hash}(14) = 14 \bmod 7 = 0$$

$$\text{hash}(21) = 21 \bmod 7 = 0$$



**Collision** occurs!

Continue until 21 is found or the **next empty slot** is reached

(wrapping around when we reach the last slot).

## 5.2 Linear Probing: Insert 1

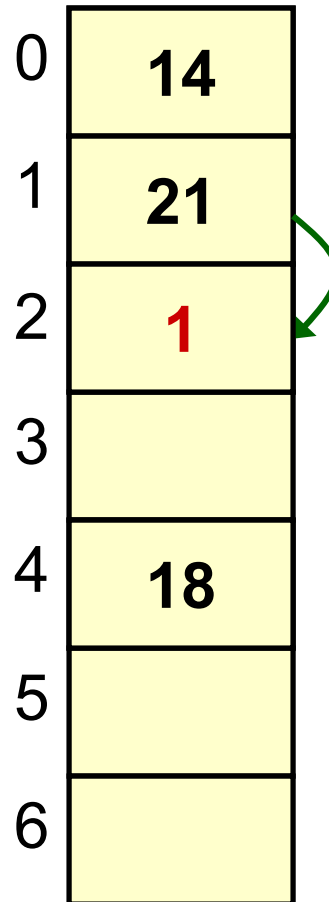
**$\text{hash}(k) = k \bmod 7$**

$\text{hash}(18) = 18 \bmod 7 = 4$

$\text{hash}(14) = 14 \bmod 7 = 0$

$\text{hash}(21) = 21 \bmod 7 = 0$

$\text{hash}(1) = 1 \bmod 7 = 1$



0	14
1	21
2	1
3	
4	18
5	
6	

Collides with 21  
(hash value 0).

What should we do?  
Look for **next empty slot**.

## 5.2 Linear Probing: Insert 35

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(18) = 18 \bmod 7 = 4$$

$$\text{hash}(14) = 14 \bmod 7 = 0$$

$$\text{hash}(21) = 21 \bmod 7 = 0$$

$$\text{hash}(1) = 1 \bmod 7 = 1$$

$$\text{hash}(35) = 35 \bmod 7 = 0$$

0	14
1	21
2	1
3	35
4	18
5	
6	

Collision, need to check **next 3 slots**.



## 5.2 Linear Probing - Deletion

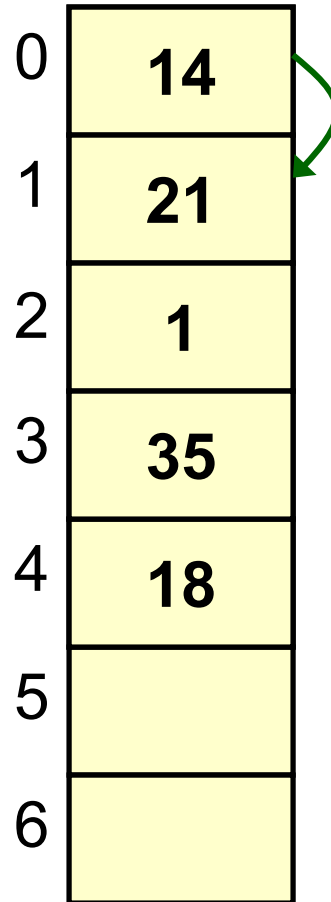
$$\text{hash}(k) = k \bmod 7$$

0	14
1	21
2	1
3	35
4	18
5	
6	

## 5.2 Linear Probing: Delete 21

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(21) = 0$$



0	14
1	21
2	1
3	35
4	18
5	
6	

1. Find 21
2. If 21 not found do nothing
3. If 21 found  
~~delete 21~~

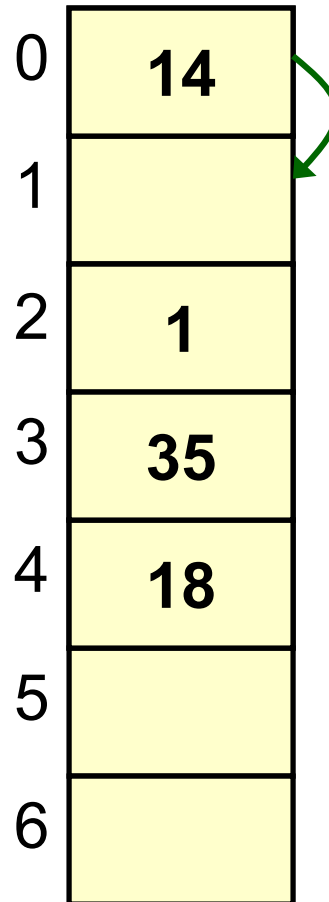
We **cannot** simply **remove** a value, because it can affect **find()**!

## 5.2 Linear Probing: Find 35

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(35) = 0$$

Hence for deletion, **cannot** simply remove the key value!



0	14
1	
2	1
3	35
4	18
5	
6	

We **cannot** simply **remove** a value, because it can affect **find()**!

35 NOT found!  
**Incorrect!**

## 5.2 How to delete?

- **Lazy** Deletion
- Use **three** different **states** of a slot
  - Occupied
  - Occupied but mark as deleted
  - Empty
- When a value is removed from linear probed hash table, we just **mark** the status of the slot as “**deleted**”, instead of emptying the slot.

## 5.2 Linear Probing: Delete 21

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(21) = 0$$

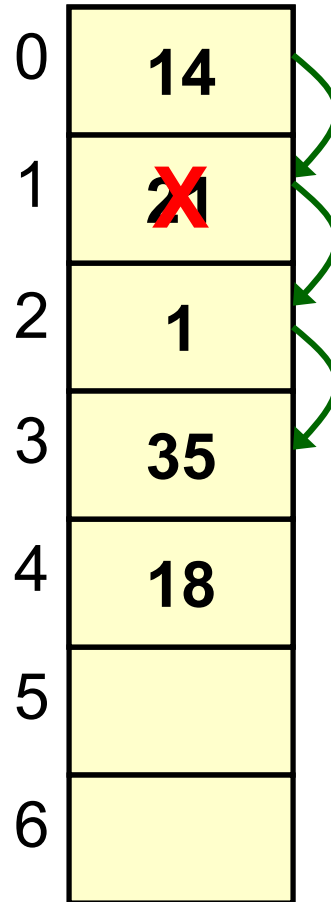
0	14
1	<del>21</del>
2	1
3	35
4	18
5	
6	

Slot 1 is occupied but now **marked as deleted**.

## 5.2 Linear Probing: Find 35

$\text{hash}(k) = k \bmod 7$

$\text{hash}(35) = 0$



0	14
1	<del>21</del>
2	1
3	35
4	18
5	
6	

Found 35

Now we can find 35

## 5.2 Linear Probing: Insert 15 (1/2)

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(15) = 1$$

0	14
1	<del>21</del>
2	1
3	35
4	18
5	
6	

Slot 1 is marked as deleted.

We **continue to search** for 15, and found that 15 is not in the hash table (total 5 probes).

So, we insert this new value 15 into the slot that has been marked as deleted (i.e. slot 1).

## 5.2 Linear Probing: Insert 15 (2/2)

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(15) = 1$$

0	14
1	15
2	1
3	35
4	18
5	
6	

So, 15 is inserted into slot **1**, which was marked as deleted.

**Note:** We should insert a new value in the **first** available slot so that the find operation for this value will be the fastest.



## 5.2 Linear Probing

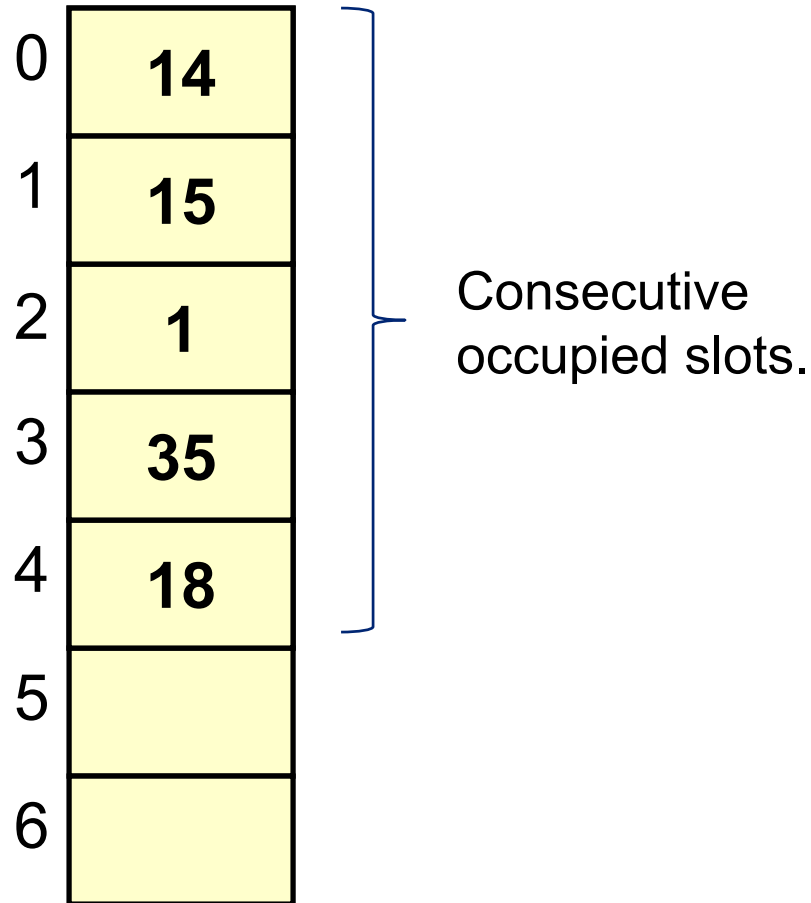
The **probe sequence** of this linear probing is:

$$\begin{aligned} & \text{hash(key)} \\ & ( \text{hash(key)} + \mathbf{1} ) \% m \\ & ( \text{hash(key)} + \mathbf{2} ) \% m \\ & ( \text{hash(key)} + \mathbf{3} ) \% m \\ & \vdots \end{aligned}$$

## 5.2 Problem of Linear Probing

It can create many **consecutive occupied slots**, increasing the running time of find/insert/delete.

This is called **Primary Clustering**



## 5.2 Modified Linear Probing

Q: How to modify linear probing to **avoid primary clustering**?

We can modify the **probe sequence** as follows:

$$\begin{aligned} & \text{hash(key)} \\ & ( \text{hash(key)} + \mathbf{1} * \mathbf{d} ) \% m \\ & ( \text{hash(key)} + \mathbf{2} * \mathbf{d} ) \% m \\ & ( \text{hash(key)} + \mathbf{3} * \mathbf{d} ) \% m \\ & \vdots \end{aligned}$$

where  $d$  is some constant integer  $>1$  and is co-prime to  $m$ .

Note: Since  $d$  and  $m$  are co-primes, the probe sequence **covers all** the slots in the hash table.

## 5.3 Quadratic Probing

For **quadratic probing**, the probe sequence is:

$$\begin{aligned} & \text{hash(key)} \\ & ( \text{hash(key)} + \mathbf{1} ) \% m \\ & ( \text{hash(key)} + \mathbf{4} ) \% m \\ & ( \text{hash(key)} + \mathbf{9} ) \% m \\ & \vdots \\ & ( \text{hash(key)} + \mathbf{k^2} ) \% m \end{aligned}$$

## 5.3 Quadratic Probing: Insert 3

$$\text{hash}(k) = k \bmod 7$$

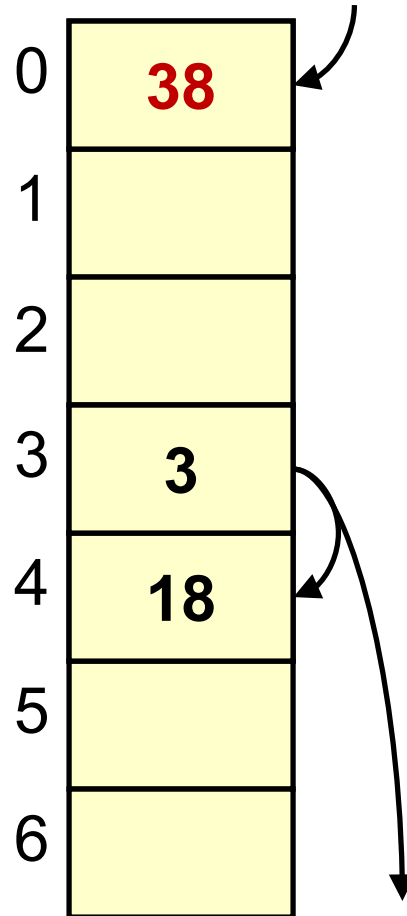
$$\text{hash}(3) = 3$$

0	
1	
2	
3	3
4	18
5	
6	

## 5.3 Quadratic Probing: Insert 38

$$\text{hash}(k) = k \bmod 7$$

$$\text{hash}(38) = 3$$



## 5.3 Theorem of Quadratic Probing

- If  $\alpha < 0.5$ , and  $m$  is prime, then we can always find an empty slot.  
( $m$  is the table size and  $\alpha$  is the load factor)
- Note:  $\alpha < 0.5$  means the hash table is less than half full.
- Q: How can we be sure that quadratic probing always terminates?
- Insert 12 into the previous example, followed by 10. See what happen?

## 5.3 Problem of Quadratic Probing

- If two keys have the **same** initial position, their probe sequences are the **same**.
- This is called **secondary clustering**.
- But it is not as bad as linear probing.



## 5.4 Double Hashing

Use 2 hash functions:

$\text{hash}(\text{key})$

$( \text{hash}(\text{key}) + 1 * \text{hash}_2(\text{key}) ) \% m$

$( \text{hash}(\text{key}) + 2 * \text{hash}_2(\text{key}) ) \% m$

$( \text{hash}(\text{key}) + 3 * \text{hash}_2(\text{key}) ) \% m$

:

$\text{hash}_2$  is called the **secondary hash function**, the number of slots to jump each time a collision occurs.

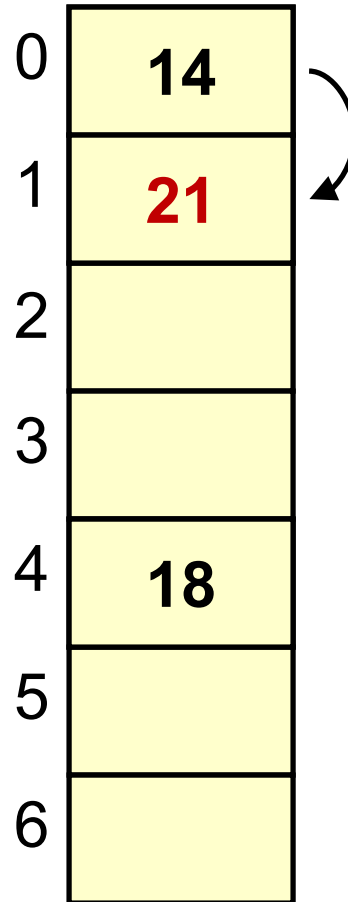
## 5.4 Double Hashing: Insert 21

$\text{hash}(k) = k \bmod 7$

$\text{hash}_2(k) = k \bmod 5$

$\text{hash}(21) = 0$

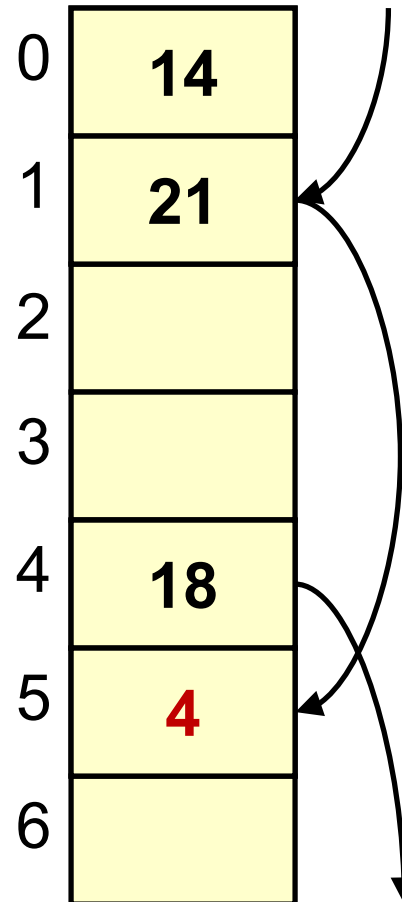
$\text{hash}_2(21) = 1$



## 5.4 Double Hashing: Insert 4

$\text{hash}(k) = k \bmod 7$   
 $\text{hash}_2(k) = k \bmod 5$

$\text{hash}(4) = 4$   
 $\text{hash}_2(4) = 4$

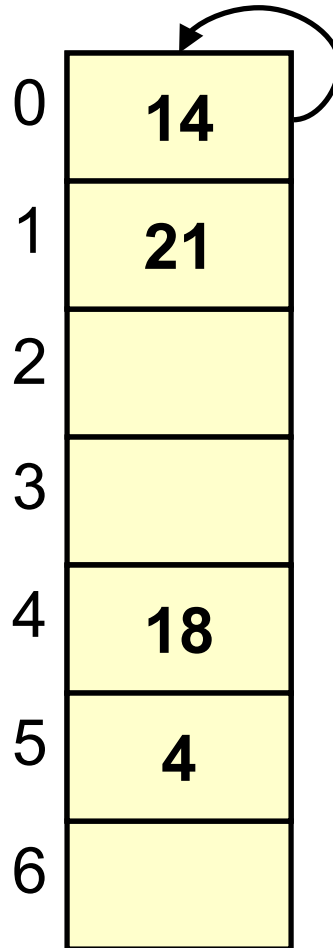


If we insert 4, the  
probe sequence is  
4, 8, 12, ...

## 5.4 Double Hashing: Insert 35

$\text{hash}(k) = k \bmod 7$   
 $\text{hash}_2(k) = k \bmod 5$

$\text{hash}(35) = 0$   
 $\text{hash}_2(35) = 0$



But if we insert 35,  
the probe sequence  
is **0, 0, 0, ...**

What is wrong?  
Since  $\text{hash}_2(35) = \mathbf{0}$ .  
**Not acceptable!**

## 5.4 Warning

- Secondary hash function must **not** evaluate to **0**!
- To solve this problem, simply change  $\text{hash}_2(\text{key})$  in the above example to:

$$\text{hash}_2(\text{key}) = 5 - (\text{key} \% 5)$$

### Note:

- If  $\text{hash}_2(k) = 1$ , then it is the same as linear probing.
- If  $\text{hash}_2(k) = d$ , where  $d$  is a constant integer  $> 1$ , then it is the same as modified linear probing.

## 5.5 Criteria of Good Collision Resolution Method

- Minimize clustering
- Always find an empty slot if it exists
- Give different probe sequences when 2 initial probes are the same (i.e. no secondary clustering)
- Fast

## 5.6 Worst case performance of hashing

- For separate chaining
  - $O(n)$  time for find/insert/delete
  - Such a case is when all items hash to one index so you have a linked list of size  $n$
- For open addressing
  - $O(n)$  time for find/insert/delete
  - Such a case is when you have to probe every slot in the table to determine you cannot insert or what is to be found/deleted is not in the table

## 5.6 Average case performance of hashing: Using Separate Chaining

- $\alpha$  (load factor) is the average size of the linked list for each slot
- Thus if  $\alpha$  is bounded, find/insert/delete will take  $O(1)$  time on average



## 5.6 Average case performance of hashing: Using Open Addressing

- Average case = average number of probes
- Assuming each probe location is generated randomly and independently so that clustering does not happen
- For each probe

Probability of finding empty slot =  $1 - \alpha$

Probability of finding non-empty slot =  $\alpha$

## 5.6 Average case performance of hashing: Using Open Addressing

- For unsuccessful find, unsuccessful delete and successful insert (need to hit an empty slot)

$$\text{Average number of probes} = \frac{1}{1 - \alpha}$$

- For successful find and successful delete

$$\text{Average number of probes} = \frac{1}{\alpha} \ln \frac{1}{1 - \alpha}$$

- Again if  $\alpha$  is bounded, find/insert/delete will take  $O(1)$  time on average

## 6 Set ADT

- A set as you have learned in high school is simply a unordered collection of items with no duplicates (with duplicates it's a multi-set)
  - E.g  $\{1,2,3\}$  is a set of 3 integers and this set is the same set as  $\{3,1,2\}$ , since order does not matter
- Some simple Set operations include the following
  - $\text{find}(x)$  – retrieve  $x$  from the set if it exist in the set
  - $\text{insert}(x)$  – insert  $x$  into the set if it doesn't already exist in set
  - $\text{remove}(x)$  – remove  $x$  from the set if it exist in the set
  - $\text{union}(s)$  – return union of this set with another set  $s$
  - $\text{intersect}(s)$  – return intersection of this set with another set  $s$

## 6 Using Hashtable for simple Set

- HashTable can easily and efficiently implement a Set ADT If we do not need complex operations like set intersection and union

Set Operations	HashTable implementation	Time complexity
find(x)	find(x)	Average $O(1)$
Insert(x)	insert(x,x) – make <key,value> pair the same	Average $O(1)$
remove(x)	remove(x)	Average $O(1)$

# 7 Summary

- How to hash? Criteria for good hash functions?
- How to **resolve collision**?

## Collision resolution techniques:

- ❑ separate chaining
  - ❑ linear probing
  - ❑ quadratic probing
  - ❑ double hashing
- Problem on deletions
- **Primary** clustering and **secondary** clustering.

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# **8 Java HashMap Class**

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## 8 Class HashMap <K, V>

```
public class HashMap<K,V>  
    extends AbstractMap<K,V>  
    implements Map<K,V>, Cloneable, Serializable
```

- This class implements a hash map, which maps **keys** to **values**. Any non-null object can be used as a key or as a value.  
    **e.g.** We can create a hash map that maps people names to their ages. It uses the names as keys, and the ages as the values.
- The **AbstractMap** is an abstract class that provides a skeletal implementation of the **Map** interface.
- Generally, the default **load factor** (**0.75**) offers a good tradeoff between time and space costs.
- The default HashMap capacity is **16**.

# 8 Class HashMap <K, V>

## ■ Constructors summary

### □ HashMap()

Constructs an empty HashMap with a default initial capacity (16) and the default load factor of 0.75.

### □ HashMap(int initialCapacity)

Constructs an empty HashMap with the specified initial capacity and the default load factor of 0.75.

### □ HashMap(int initialCapacity, float loadFactor)

Constructs an empty HashMap with the specified initial capacity and load factor.

### □ HashMap(Map<? extends K, ? extends V> m)

Constructs a new HashMap with the same mappings as the specified Map.



## 8 Class HashMap <K, V>

### Some methods

- `void clear()`  
Removes all of the mappings from this map.
- `boolean containsKey(Object key)`  
Returns true if this map contains a mapping for the specified key.
- `boolean containsValue(Object value)`  
Returns true if this map maps one or more keys to the specified value.
- `V get(Object key)`  
Returns the value to which the specified key is mapped, or null if this map contains no mapping for the key.
- `V put(K key, V value)`  
Associates the specified value with the specified key in this map.
- ...

## 8 Example

- **Example:** Create a hashmap that maps people names to their ages. It uses **names** as **key**, and the **ages** as their **values**.

```
HashMap<String, Integer> hm = new HashMap<String, Integer>();  
// placing items into the hashmap  
hm.put("Mike", 52);  
hm.put("Janet", 46);  
hm.put("Jack", 46);  
// retrieving item from the hashmap  
System.out.println("Janet => " + hm.get("Janet"));
```

TestHash.java

The output of the above code is:

Janet => 46

---

End of file

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