

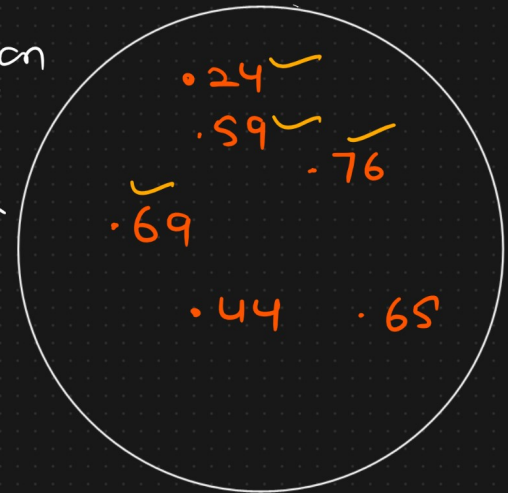
$$hf(v) = v \% m$$

## Collision Resolution Technique

key	value
0	
1	
2	
3	
4	24
5	
6	76
7	
8	
9	39

hash function

$v \% m$



Advantage

We can store infinite num of values

Limitation

Collision

search  $\rightarrow O(n)$

2) Extra space outside of hash-table (space is available inside hash

1) chaining  $\rightarrow$  Linked List (1 table)

2) Open addressing  $\rightarrow$  1) Linear Probing (2)

2) Quadratic Probing (3)

3) Double Hashing (4)

$m = 10$

value = 57, 67, 97, 45, 62, 107

Hash Table

key	value
0	-
1	-
2	5000
3	-
4	-
5	4000
6	-
7	1000
8	-
9	-

chaining

5000

57 | null

$$57 \% 10 = 7, 97 \% 10 = 7$$

$$67 \% 10 = 7, 45 \% 10 = 5$$

$$62 \% 10 = 2, 107 \% 10 = 7$$

4000

45 | null

1000

2000

3000

6000

57 | 2000

67 | 3000

97 | 6000

107 | null

Linked List/chain

# Linear Probing

65

values = 50, 75, 99, 20, 35, 88, 45, 23, 55, 67

$$hf(v) = v \% m$$

$$LP(v, i) = (hf(v) + i) \% m$$

size of hash  
table

# collisions

Hash Table

key	value
0	50
1	20
2	55
3	23
4	67
5	75
6	35
7	45
8	88
9	99

$$LP(20, 1) = (0 + 1) \% 10 = 1$$

$$LP(35, 1) = (5 + 1) \% 10 = 6$$

$$LP(45, 1) = (5 + 1) \% 10 = 6$$

$$LP(45, 2) = (5 + 2) \% 10 = 7$$

$$LP(55, 1) = (5 + 1) \% 10 = 6$$

$$LP(55, 2) = (5 + 2) \% 10 = 7$$

$$LP(55, 3) = (5 + 3) \% 10 = 8$$

$$LP(55, 4) = (5 + 4) \% 10 = 9$$

$$LP(55, 5) = (5 + 5) \% 10 = 0$$

$$LP(55, 6) = (5 + 6) \% 10 = 1$$

$$LP(55, 7) = (5 + 7) \% 10 = 2$$

Search

time complexity

Worst case  $\rightarrow O(n)$  (55)

Best case  $\rightarrow O(1)$  (75)

55  $\rightarrow hf(55) = 5$

65  $\rightarrow hf(65) = 5$

Primary clustering

## Quadratic Probing

Value = 50, 75, 99, 20, 35, 88, 45, 23, 55, 67

size of  
hash  
table

$$c_1 = c_2 = 1$$

$$Q P(v, i) = (h f(v) + c_1 i + c_2 i^2) \% m$$

Hash  
Table

key	value
0	50
1	45
2	20
3	23
4	
5	75
6	
7	35
8	88
9	99

# collisions

$$Q P(20, 1) = (0 + 1 + 1) \% 10$$

$$Q P(35, 1) = (5 + 1 + 1) \% 10 = 7$$

$$Q P(45, 1) = (5 + 1 + 1) \% 10 = 7$$

$$Q P(45, 2) = (5 + 2 + 4) \% 10 = 11 \% 10 = 1$$

$$Q P(55, 3) = (5 + 3 + 9) \% 10 = 7$$

$$Q P(55, 4) = (5 + 4 + 16) \% 10 = 5$$

$$Q P(55, 5) = (5 + 5 + 25) \% 10 = 5$$

Limitation → loss of data (55), Secondary clustering,  
search →  $O(m)$



## Double Hashing

value = 50, 75, 99, 20, 35, 88, 45, 23, 55, 67

$$DH(v, i) = \left( hf_1(v) + i hf_2(v) \right) \% m$$

$\nearrow$  H collisions

$$hf_2(v) = 1 + v \% (m-1)$$

	0	50	
—	1		
—	2		
—	3		
—	4		
—	5	75	
—	6		
—	7		
—	8		
—	9	99	

(20)  $hf_2(20) = 1 + 20 \% 8$   
 $= 1 + 4$

$$hf_1(20) = 0 \quad = 5$$

$$DH(20, 1) = (0 + 5) \% 10$$
$$= 5$$

$$DH(20, 2) = (0 + 2 * 5) \% 10$$
$$= 0$$

$$DH(20, 3) = (0 + 3 * 5) \% 10$$
$$= 5$$

↳ Loss of Data

↳ Search  $\rightarrow O(m)$