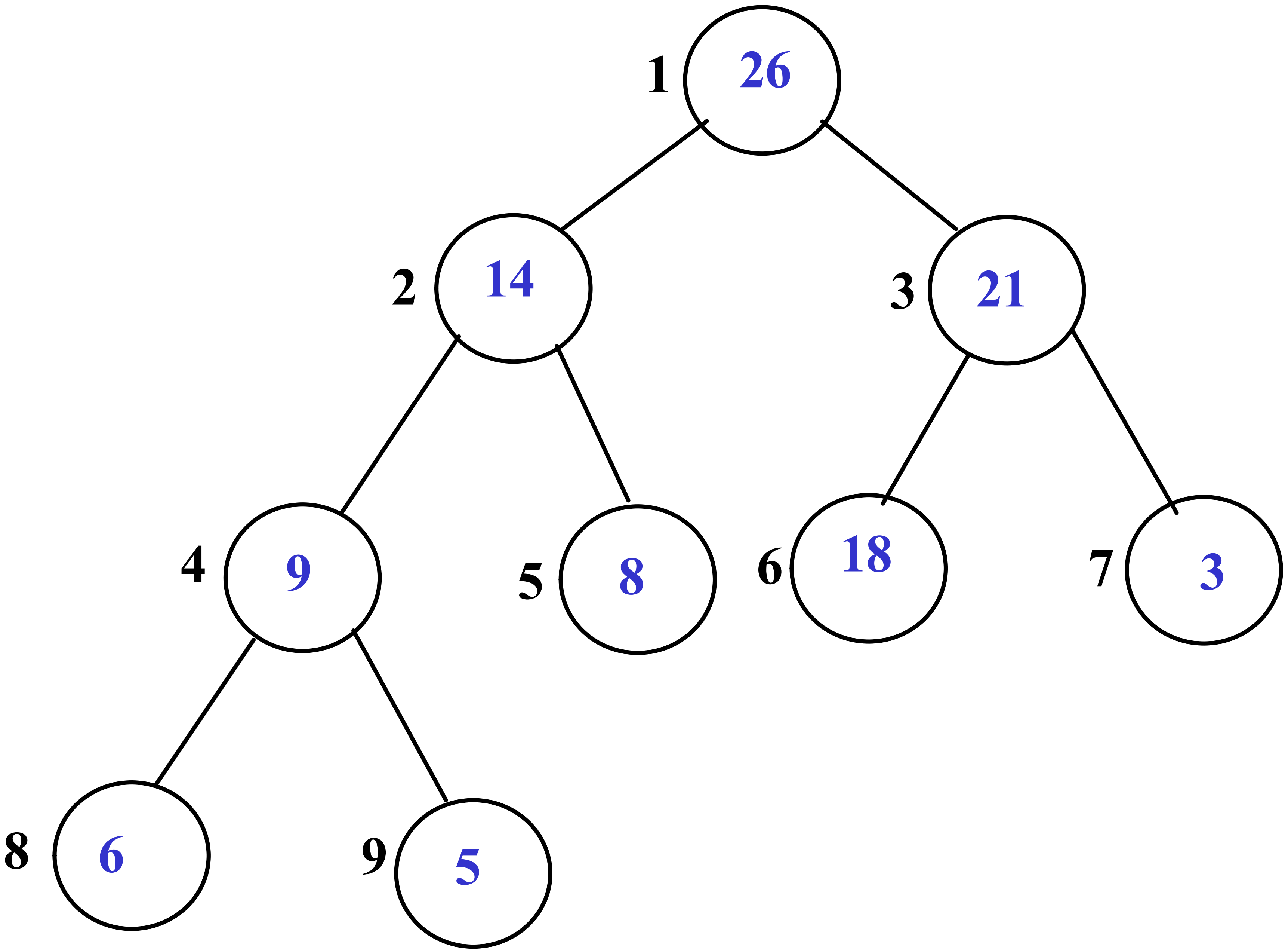
Size=9
9/2 = 4

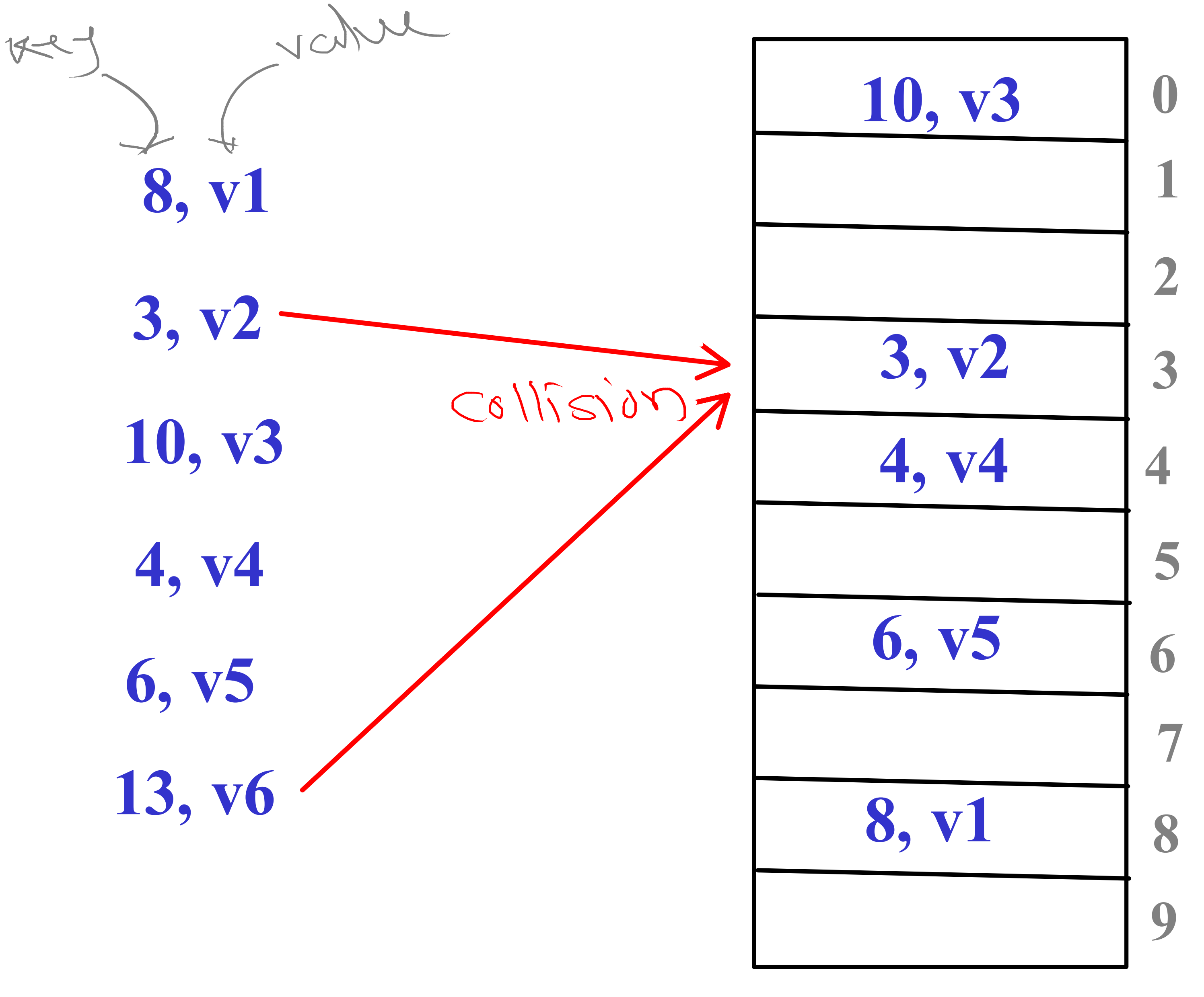


Heapify

Time : O(n)

6	26	21	14	8	18	3	9	5
1	2	3	4	5	6	7	8	9

Hashing



10, v3	0
	1
	2
3, v2	3
4, v4	4
	5
6, v5	6
	7
8, v1	8
	9

Hash Table

$h(k) = k \% size$

$h(8) = 8 \% 10 = 8$

$h(3) = 3 \% 10 = 3$

$h(10) = 10 \% 10 = 0$

$h(4) = 4 \% 10 = 4$

$h(6) = 6 \% 10 = 6$

$h(13) = 13 \% 10 = 3$

```
insert/add : — O(1)
    slot = k % size;
    arr[slot] = entry;
search : — O(1)
    slot = k % size
    return arr[slot].vale
```

Closed Addressing/ Seperate Chaining / Chaining

8, v1

3, v2

10, v3

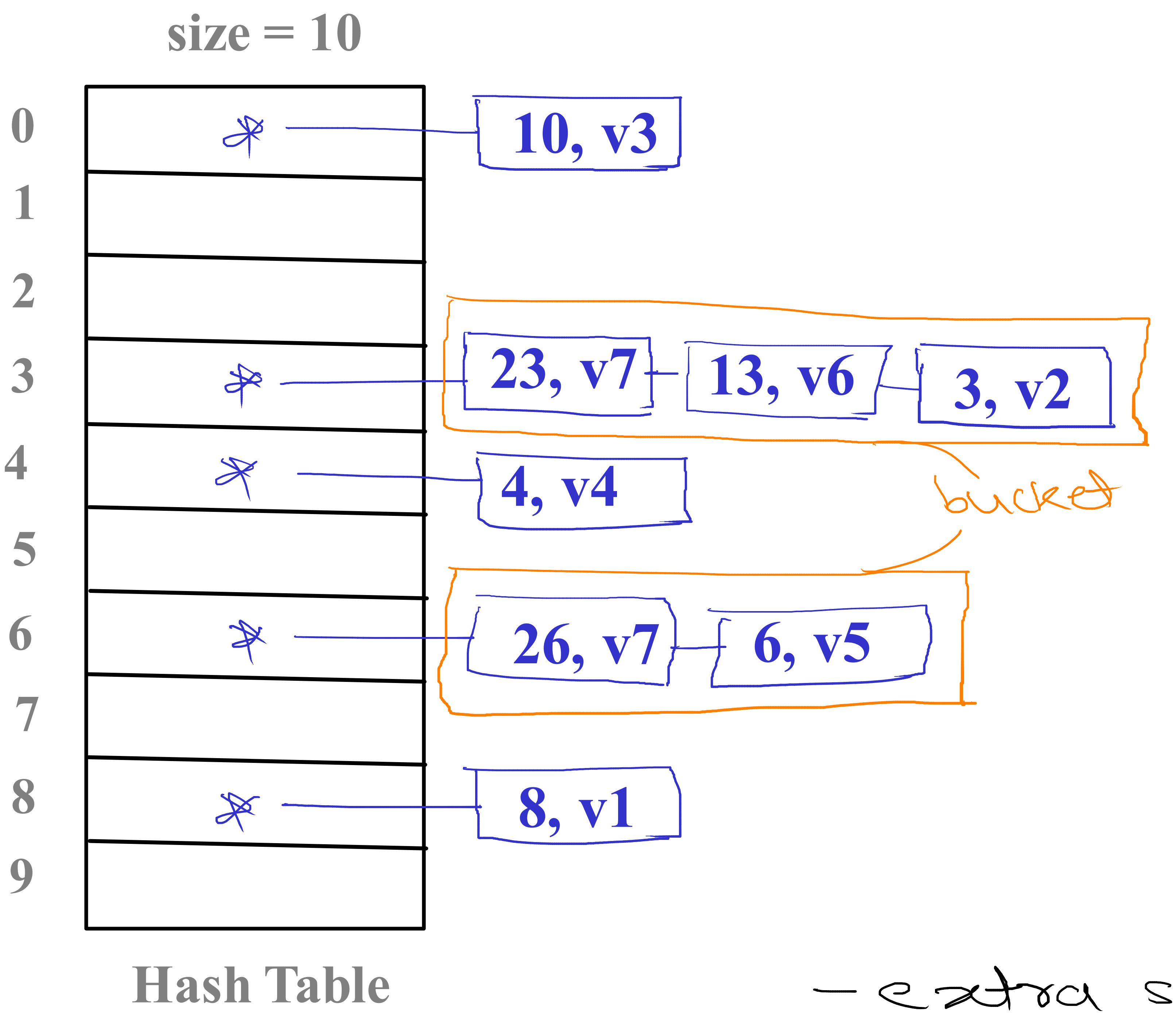
4, v4

6, v5

13, v6

23, v7

26, v7



h(k) = k % size

h(8) = 8%10 = 8

h(3) = 3%10 = 3

h(10) = 10%10 = 0

h(4) = 4%10 = 4

h(6) = 6%10 = 6

h(13) = 13%10 = 3 ⓒ

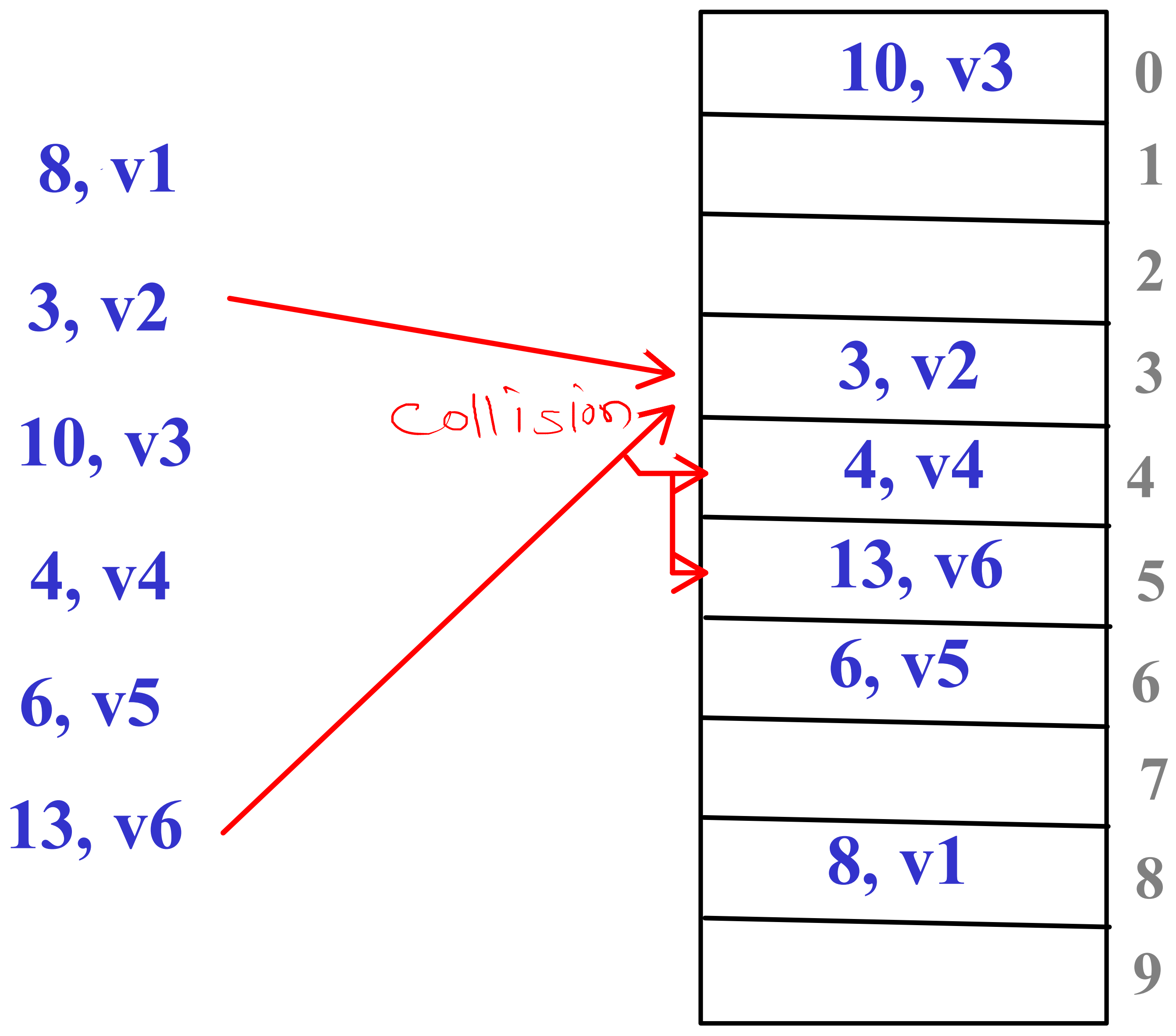
h(23) = 23%10 = 3 ⓒ

h(26) = 26%10 = 6 ⓒ

- extra space is needed
- data(key-value) is kept outside the table
- Worst case: O(n)
  ↳ if all keys yield same slot

Open Addressing - Linear Probing

size = 10



Index	Slot
0	10, v3
1	
2	
3	3, v2
4	4, v4
5	13, v6
6	6, v5
7	
8	8, v1
9	

Hash Table

$h(k) = key \ \% \ size$

$h(k, i) = [\ \underline{h(k)} + \underline{f(i)}\ ] \ \% \ size$

$f(i) = \underline{i}$

where i = 1, 2, 3, ...

↳ probe number

$h(8) = 8 \% 10 = 8$

$h(3) = 3 \% 10 = 3$

$h(10) = 10 \% 10 = 0$

$h(4) = 4 \% 10 = 4$

$h(6) = 6 \% 10 = 6$

$h(13) = 13 \% 10 = 3$ (collision)

$h(13,1) = [3+1] \% 10$

$= 4$ (1st probe)(collision)

$h(13,2) = [3+2] \% 10$

$= 5$ (2nd probe)

Probing – find new slot for key when collision is occured

Primary clustering – take long runs of filled slots "near" key position

Open Addressing - Quadratic Probing

8, v1

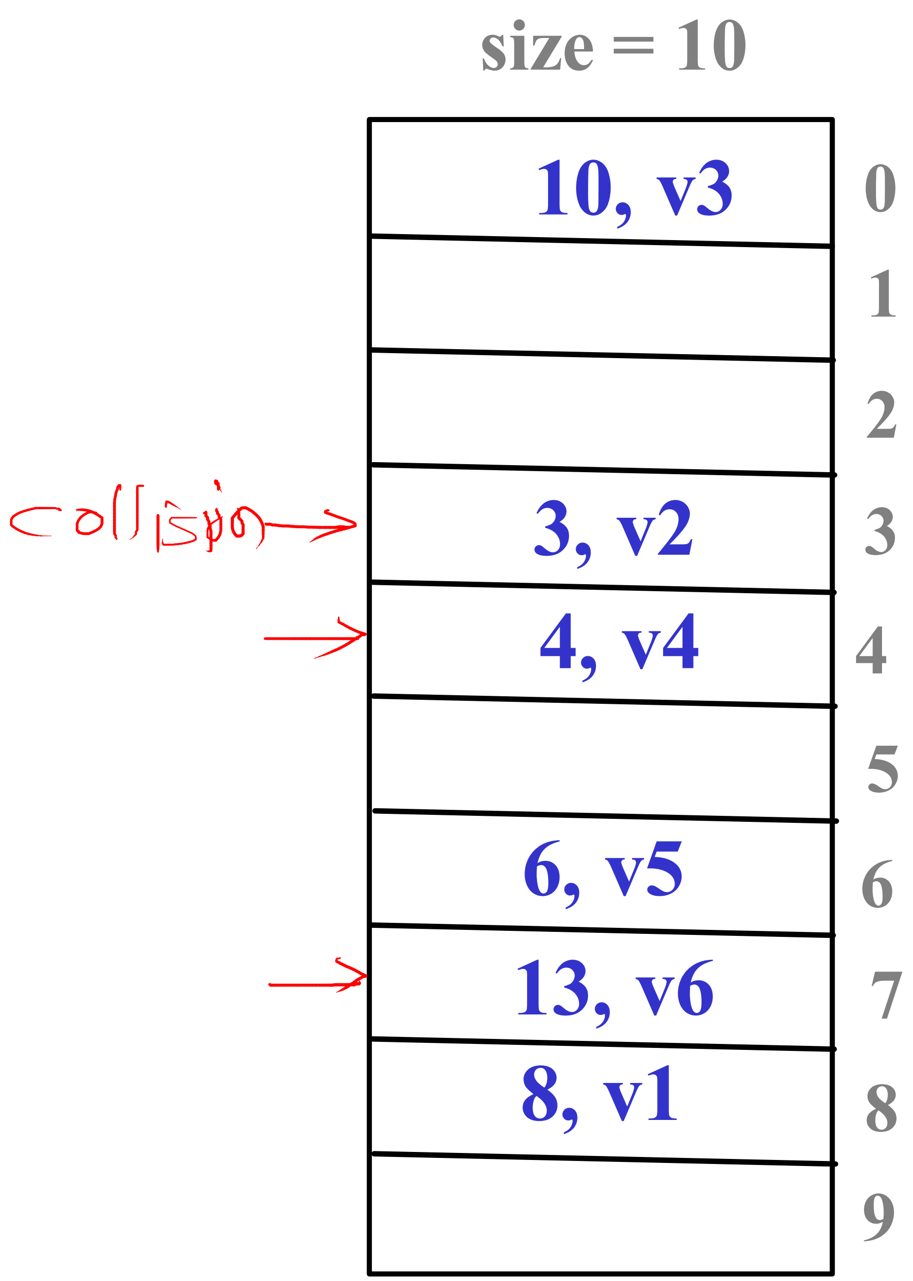
3, v2

10, v3

4, v4

6, v5

13, v6



0	10, v3
1	
2	
3	3, v2
4	4, v4
5	
6	6, v5
7	13, v6
8	8, v1
9	

Hash Table

$h(k) = key \% size$

$h(k, i) = [\ h(k) + f(i)\ ] \% size$

$f(i) = i^2$

where i = 1, 2, 3, ...

↳probe number

$h(8) = 8 \% 10 = 8$

$h(3) = 3 \% 10 = 3$

$h(10) = 10 \% 10 = 0$

$h(4) = 4 \% 10 = 4$

$h(6) = 6 \% 10 = 6$

$h(13) = 13 \% 10 = 3$

$h(13,1) = [3 + 1] \% 10$

$= 4$ (1st probe) (collision)

$h(13,2) = [3 + 4] \% 10$

$= 7$ (2nd probe)

Secondary clustering — take long runs of filled slots "away" key position

Open Addressing - Quadratic Probing

23, v7

33, v8

size = 10

10, v3	0
	1
23, v7	2
3, v2	3
4, v4	4
	5
6, v5	6
13, v6	7
8, v1	8
33, v8	9

Hash Table

h(k) = key % size

h(k, i) = [h(k) + f(i)] % size

f(i) = i^2

where i = 1, 2, 3, ...

$h(23) = 23 \% 10 = 3 \boxed{c}$

$h(23,1) = [3+1] \% 10 = 4 \boxed{c}$ (1st)

$h(23,2) = [3+4] \% 10 = 7 \boxed{c}$ (2nd)

$h(23,3) = [3+9] \% 10 = 2$ (3rd)

$h(33) = 33 \% 10 = 3$

$h(33,1) = [3+1] \% 10 = 4$

$h(33,2) = [3+4] \% 10 = 7$

$h(33,3) = [3+9] \% 10 = 2$

$h(33,4) = [3+16] \% 10 = 9$

Hashing - Double Hashing

8, v1

3, v2

10, v3

25, v6

size = 11

	0
	1
	2
3, v2	3
	4
	5
25, v6	6
	7
8, v1	8
	9
10, v3	10

Hash Table

$h1(k) = key \% size$

$h2(k) = 7 - (key \% 7)$

$h(k, i) = [h1(k) + i * h2(k)] \% size$

$h1(8) = 8 \% 11 = 8$

$h1(3) = 3 \% 11 = 3$

$h1(10) = 10 \% 11 = 10$

$h1(25) = 25 \% 11 = 3$ $\textcircled{c}$

$h2(25) = 7 - 4 = 3$

$h(25, 1) = [3 + 1 * 3] \% 11$

$= 6$ (1^{st} probe)

Rehashing

$$\text{Load Factor} = \frac{n}{N}$$

(λ)

$(0 \text{ to } 1)$

$$\begin{tikzcd} 10 \arrow[r] \arrow[d] & 7 \\ 20 & \boxed{\begin{array}{l} 10 * 0.7 \\ = 7 \end{array}} \arrow[u] \end{tikzcd}$$

n - Number of elements (key value pairs) in hash table
N - Number of slots in hash table

if n < N	Load factor < 1	- free slots are available
if n = N	Load factor = 1	- no free slots
if n > N	Load factor > 1	- can not insert at all

- Rehashing is make the hash table size twice of existing size if hash table is 70 or 75 % full

- In rehashing existing key value pairs are again mapped according to new hash table size