Session-1
Hashing

TABLES

- A table has several fields (types of information)
  - A telephone book may have fields name, address, phone number
  - A user account table may have fields user id, password, home folder
- To find an entry in the table, you only need know the contents of one of the fields (not all of them). This field is the key.
  - In a telephone book, the key is usually name
  - In a user account table, the key is usually user id
- Ideally, a key uniquely identifies an entry
- If the key is name and no two entries in the telephone book have the same name, the key uniquely identifies the entries.

Table ADT : Operations

- insert: given a key and an entry, inserts the entry into the table

- find: given a key, finds the entry associated with the key

- remove: given a key, finds the entry associated with the key, *and removes it*

Also:

- getIterator: returns an iterator, which visits each of the entries one by one (the order may or may not be defined) *etc.*

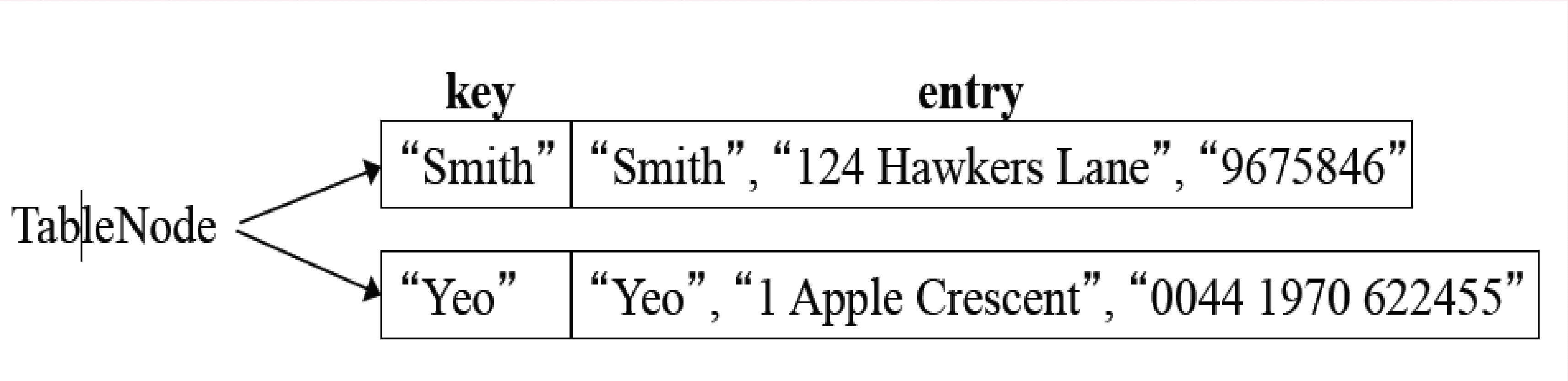
Implementation of Table

Our choice of representation for the Table ADT depends on the answers to the following

- How often are entries inserted and removed?
- How many of the possible key values are likely to be used?
- Is the table small enough to fit into memory?
- How long will the table exist?

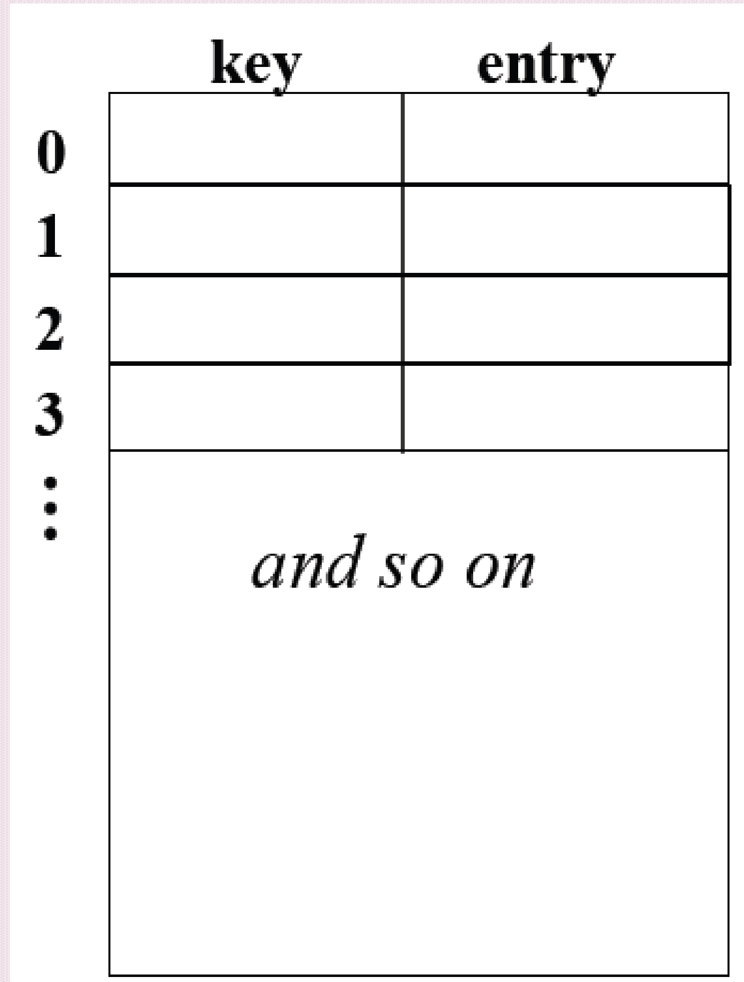
Table Node : Key and Entry

- For searching purposes, it is best to store the key and the entry separately (even though the key's value may be inside the entry)



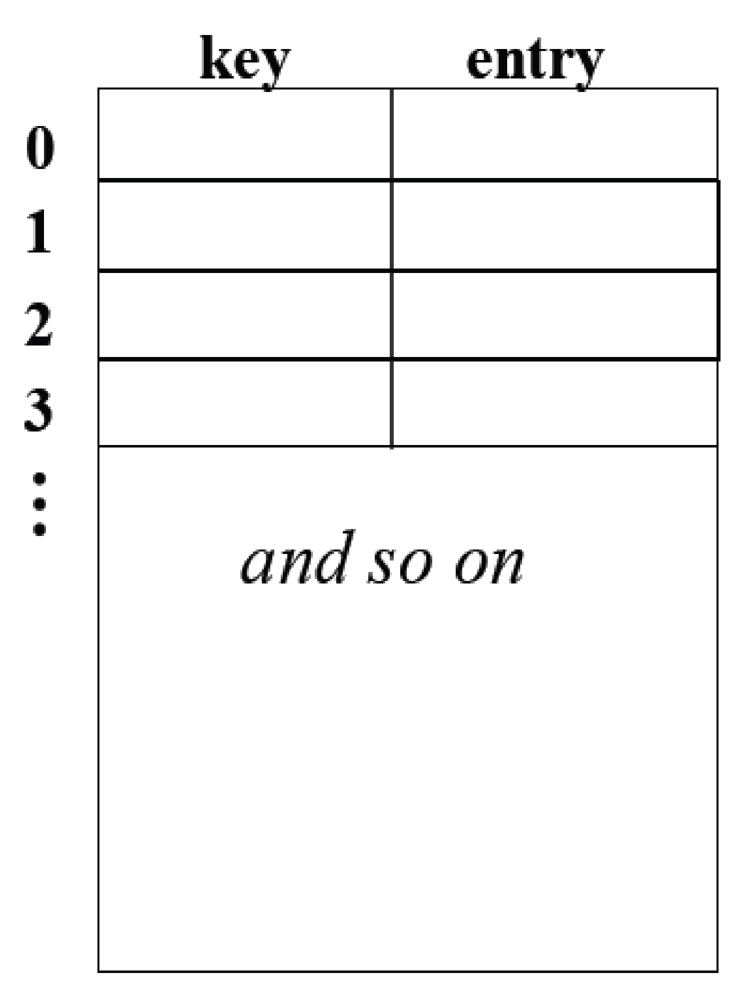
Implementation 1: Unsorted Sequential Array

- An array in which TableNodes are stored consecutively in *any order*
- **insert: add to back of array; O(1)**
- **find: search through the keys one at a** time, potentially all of the keys; O(*n)*
- **remove: find + replace removed node** with last node; O(*n)*



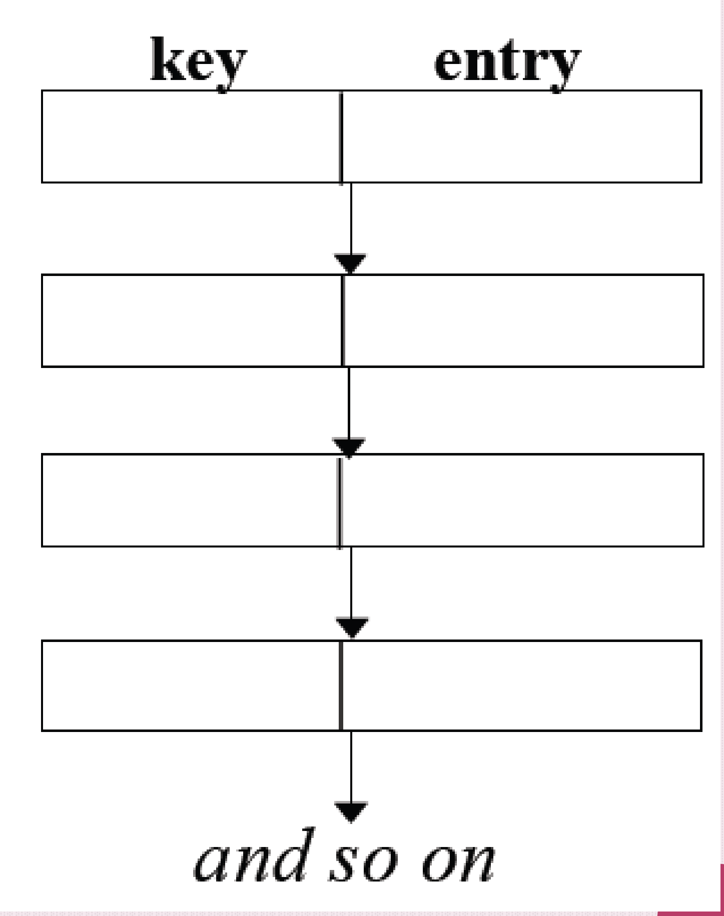
Implementation 2: Sorted Sequential Array

- An array in which TableNodes are stored consecutively, *sorted by key*
- **insert: add in sorted order; O(*n*)**
- **find: binary search; O(log *n*)**
- **remove: find, remove node and shuffle** down; O(*n*)
- **We can use binary search because the array elements are sorted**



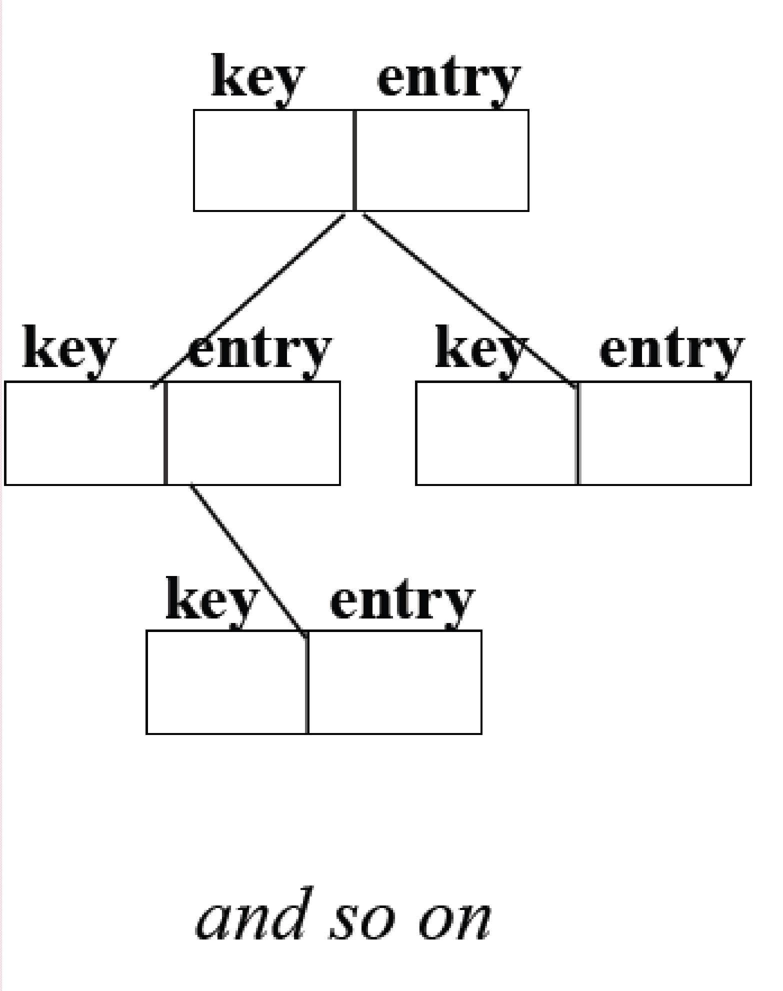
Implementation 3: using Linked List (Sorted / Unsorted)

- TableNodes are again stored consecutively
- **insert: add to front; O(1)** *or O(n) for a sorted list*
- **find: search through potentially all** the keys, one at a time; O(n) *still O(n) for a sorted list*
- **remove: find, remove using pointer** alterations; O(n)



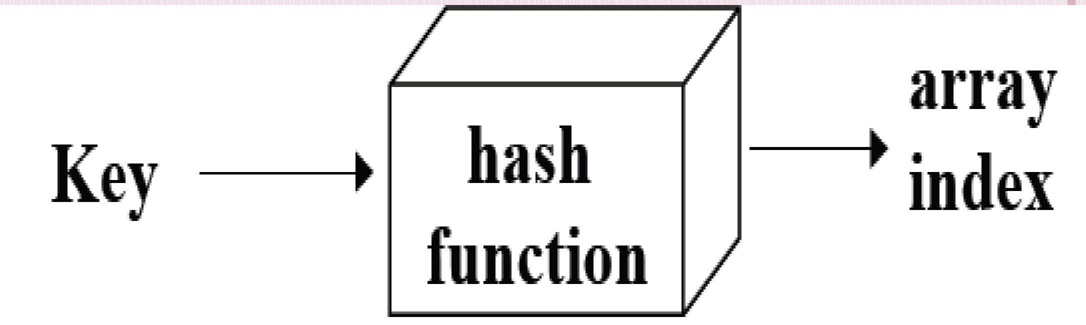
IMPLEMENTATION 4: USING AVL TREE

- An AVL tree, ordered by key
- **insert: a standard insert; O(log *n*)**
- **find: a standard find (without** removing, of course); O(log *n)*
- **remove: a standard remove; O(log *n*)**
- O(log *n*) *is very good…* …but O(1) would be even better!



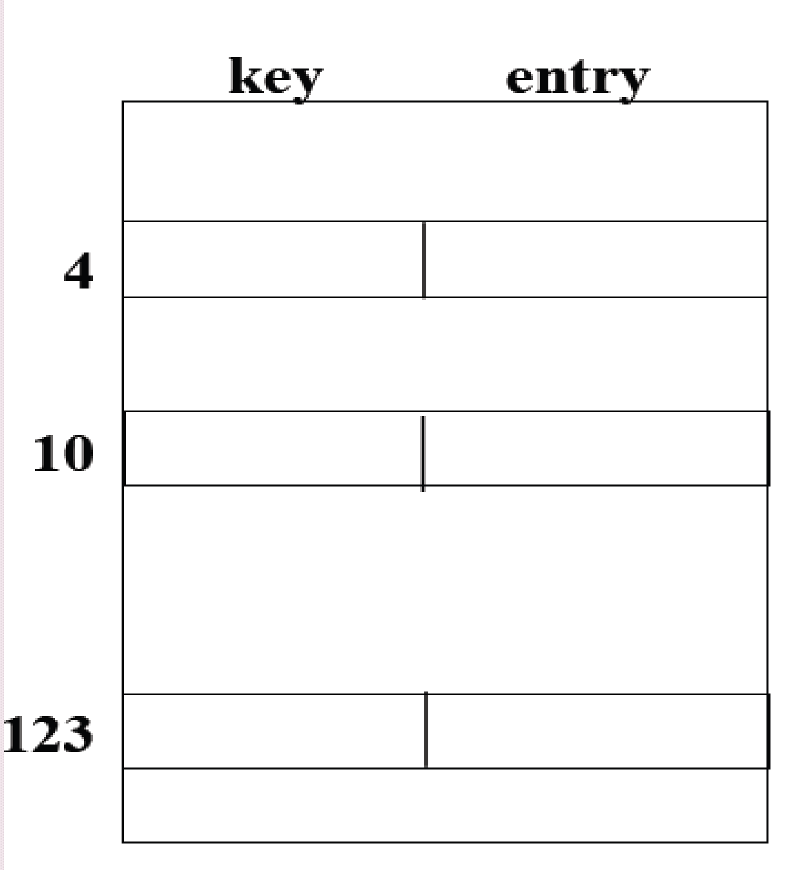
Implementation 5: Hashing

- An array in which TableNodes are ***not*** stored consecutively - their place of storage is calculated using the key and a *hash function*



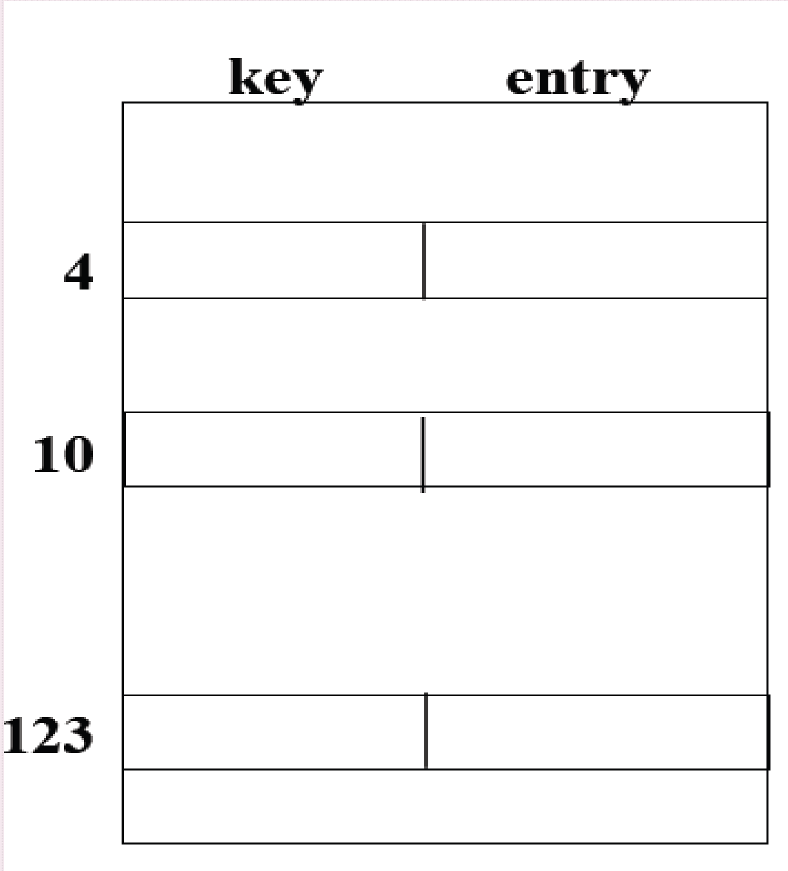
- *Hashed key: the result of applying a hash* function to a key

- Keys and entries are scattered throughout the array



Implementation 5: Hashing

- array in which TableNodes are ***not*** stored consecutively - their place of storage is calculated using the key and a *hash function*
- **insert: calculate place of storage, insert** TableNode; O(1)
- **find: calculate place of storage, retrieve** entry; O(1)
- **remove: calculate place of storage, set it** to null; O(1)
- **All are O(1) !**



HASHING EXAMPLE : FRUIT SHOP

10 stock details, 10 table positions **key entry**

Stock numbers are between 0 and 1000

Use *hash function: stock no. /100*

What if we now insert stock no. 350? Position 3 is occupied: there is a *Collision*

Collision resolution strategy: insert in the next free position (*linear probing)*

Given a stock number, we find stock by using the hash function again, and use the collision resolution strategy if necessary

	key	entry
0	85	85, apples
1		
2		
3	323	323, guava
4	462	462, pears
5	350	350, oranges
6		
7		
8		
9	912	912, papaya

Three Factors affect performance of Hashing

- The hash function
  - Ideally, it should distribute keys and entries evenly throughout the table
  - It should minimize collisions, where the position given by the hash function is already occupied
- The collision resolution strategy
  - Separate chaining: chain together several keys/entries in each position
  - Open addressing: store the key/entry in a different position
- The size of the table
  - Too big will waste memory; too small will increase collisions and may eventually force rehashing (copying into a larger table)
  - Should be appropriate for the hash function used

Examples for Hash Function

- Truncation: If students have an 9-digit identification number, take the last 3 digits as the table position
  - e.g. 925371622 becomes 622
- Folding: Split a 9-digit number into three 3-digit numbers, and add them
  - e.g. 925371622 becomes 925 + 376 + 622 = 1923
- Modular arithmetic: If the table size is 1000, the first example always keeps within the table range, but the second example does not (it should be mod 1000)
  - e.g. 1923 mod 1000 = 923

Examples for Hash Function

- Using a telephone number as a key
  - The area code is not random, so will not spread the keys/entries evenly through the table (many collisions)
  - The last 3-digits are more random

- Using a name as a key
  - Use full name rather than surname (surname not particularly random)
  - Assign numbers to the characters (e.g. a = 1, b = 2; or use Unicode values)
  - Strategy 1: Add the resulting numbers. Bad for large table size.
  - Strategy 2: Call the number of possible characters *c (e.g. c = 54 for* alphabet in upper and lower case, plus space and hyphen). Then multiply each character in the name by increasing powers of *c, and* add together.

Choosing Table Size For Minimizing Collision

- As the number of elements in the table increases, the likelihood of a *collision increases - so make the table as large* as practical

- If the table size is 100, and all the hashed keys are divisible by 10, there will be many collisions!

- Particularly bad if table size is a power of a small integer such as 2 or 10

- More generally, collisions may be more frequent if:
  - greatest common divisor (hashed keys, table size) > 1
  - Therefore, make the table size a prime number (gcd = 1)

- Collisions may still happen, so we need a *collision resolution strategy*

Collision resolution: open addressing

Probing: If the table position given by the hashed key is already occupied, increase the position by some amount, until an empty position is found

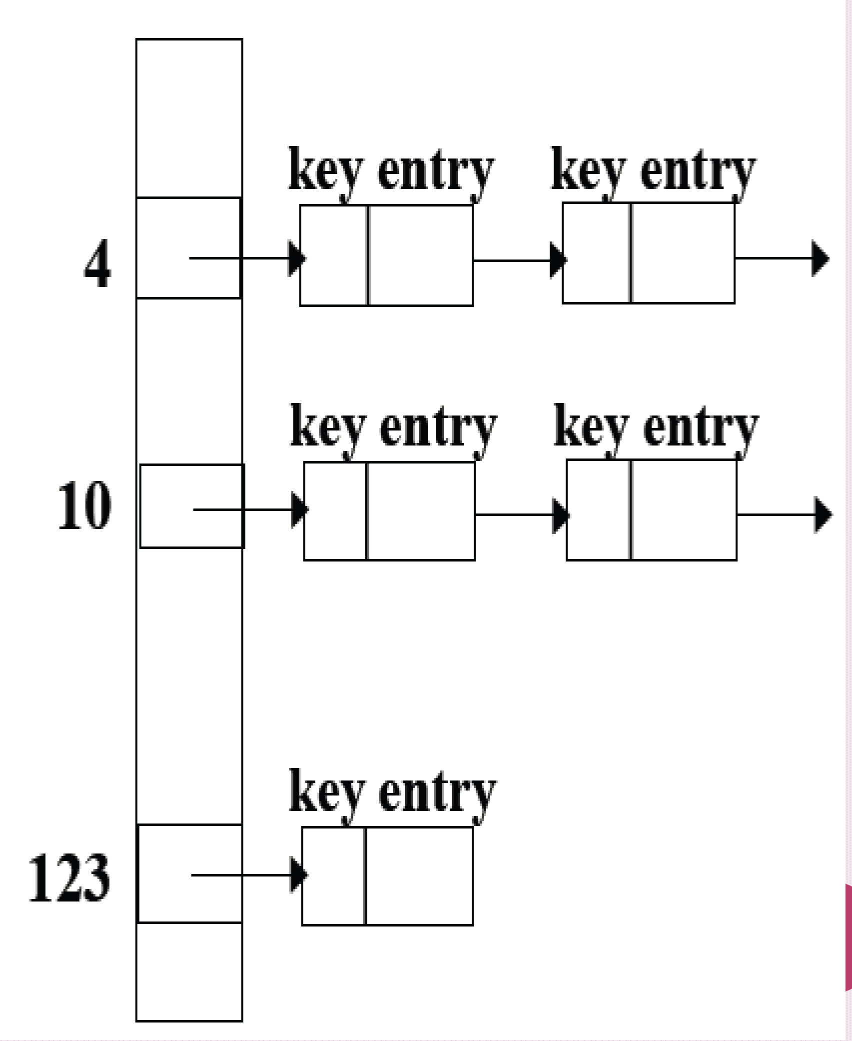
- **Linear probing**: increase by 1 each time
- **Quadratic probing**: to the original position, add 1, 4, 9, 16,…

- Use the collision resolution strategy when inserting *and when* finding (ensure that the search key and the found keys match)

COLLISION RESOLUTION : CHAINING

- Each table position is a linked list
- Add the keys and entries anywhere in the list (front easiest)
- Advantages:
  - Simpler insertion and removal
  - Array size is not a limitation (but should still minimise collisions: make table size roughly equal to expected number of keys and entries)
- Disadvantage
  - Memory overhead is large if entries are small

No need to change position!



Application of Hashing

- Compilers use hash tables to keep track of declared variables
- A hash table can be used for on-line spelling checkers — if misspelling detection (rather than correction) is important, an entire dictionary can be hashed and words checked in constant time
- Game playing programs use hash tables to store seen positions, thereby saving computation time if the position is encountered again
- Hash functions can be used to quickly check for inequality — if two elements hash to different values they must be different

Which Representation is better Than Hashing

- Hash tables are very good if there is a need for many searches in a reasonably stable table
- Hash tables are not so good if there are many insertions and deletions, or if table traversals are needed — in this case, AVL trees are better
- Also, hashing is very slow for any operations which require the entries to be sorted
- e.g. Find the minimum key