Tables and Hashing

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Tables: rows & columns of information

- 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 <u>one</u> of the fields (not <u>all</u> 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

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The 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.

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+ How should we implement a 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?

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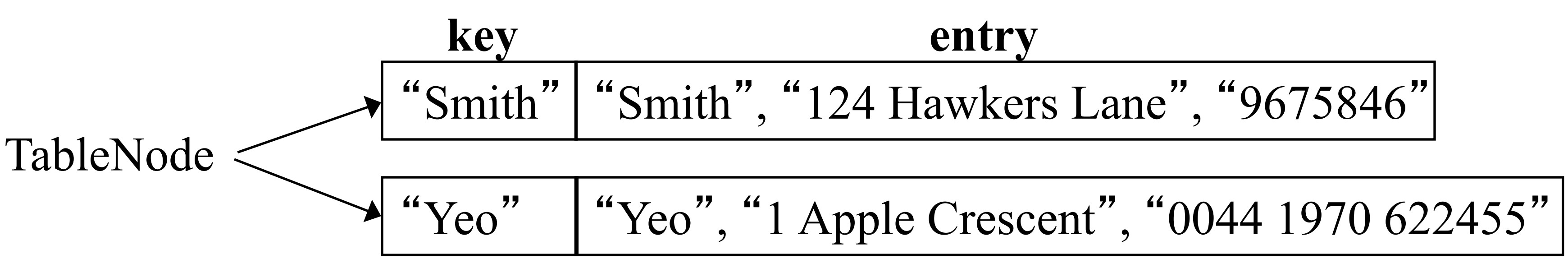
TableNode: a key and its entry

- 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)



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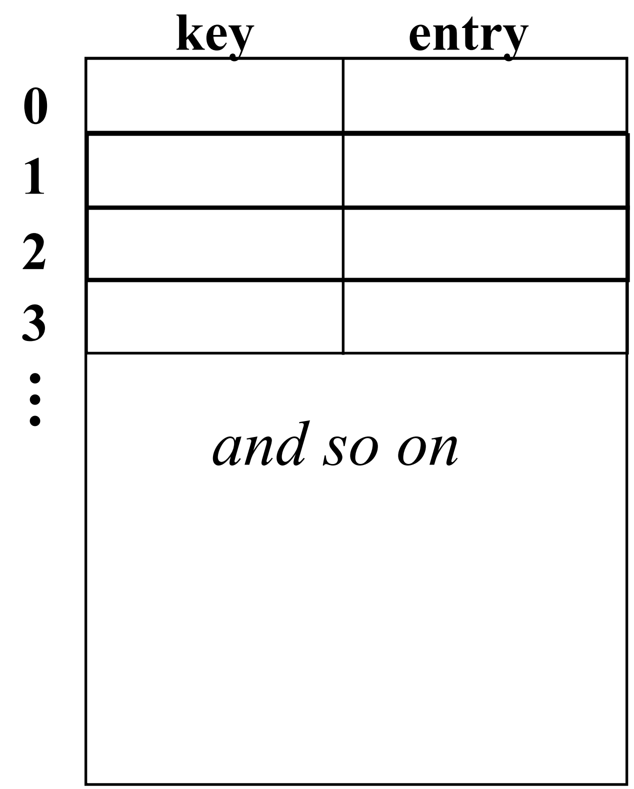
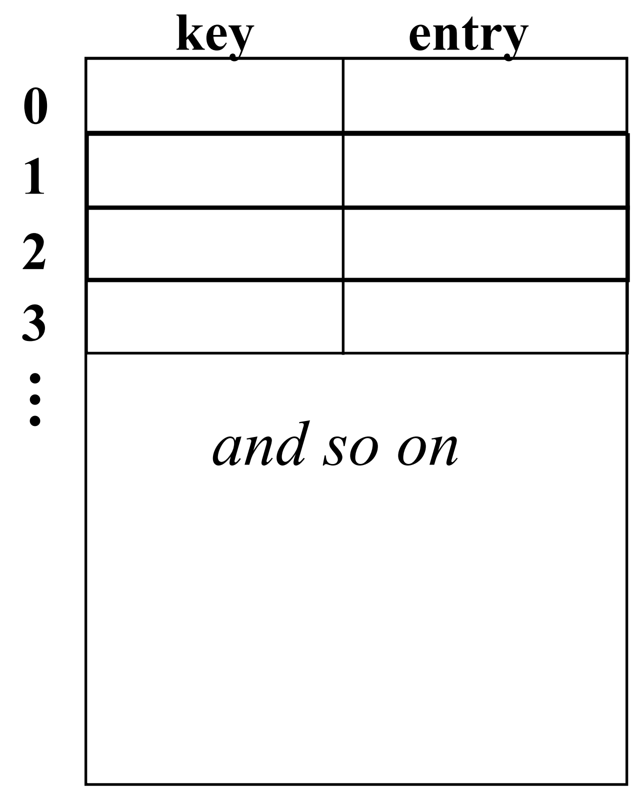
Implementation 1: unsorted sequential array

- 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 chop; O(log *n*)
- **remove**: find, remove node and shuffle down; O(*n*)



We can use binary chop because the array elements are sorted

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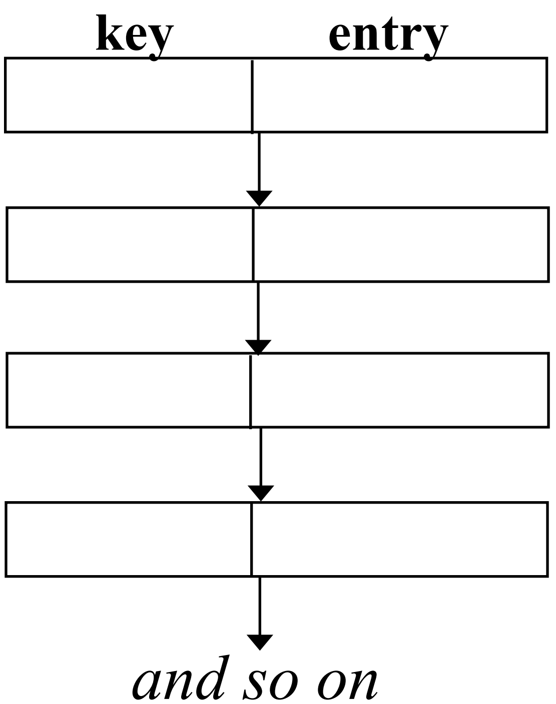
Implementation 3:linked list (unsorted or sorted)

- 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*)



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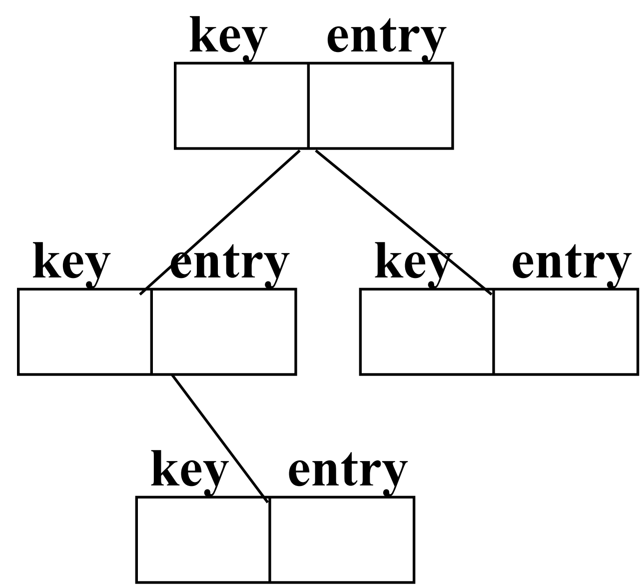
Implementation 4: AVL tree

- 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*)



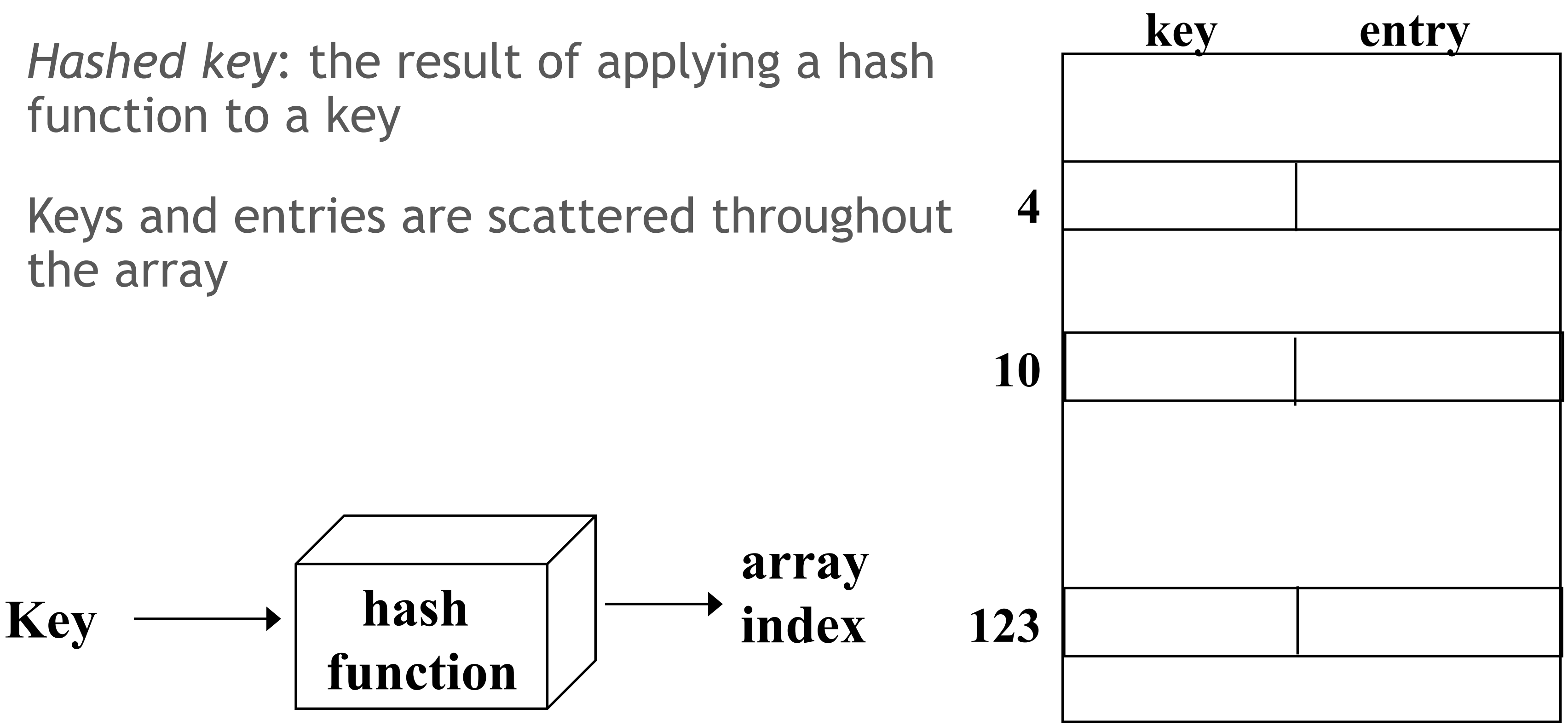
and so on

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



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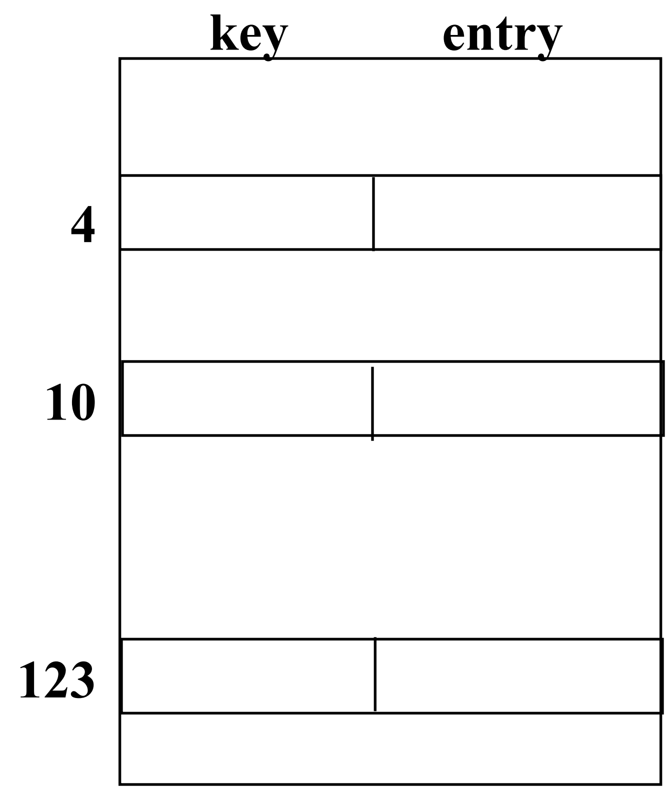
+ Implementation 5: *hashing*

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

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Hashing example: a fruit shop

- 10 stock details, 10 table positions

- 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

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+ Three factors affecting performance of hashing

- The hash function
  - Ideally, it should distribute keys and entries evenly throughout the table
  - It should minimise *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

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+ Examples of hash functions (1)

- 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

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Examples of hash functions (2)

- 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.

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Choosing the table size to minimise collisions

- 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 (1)

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

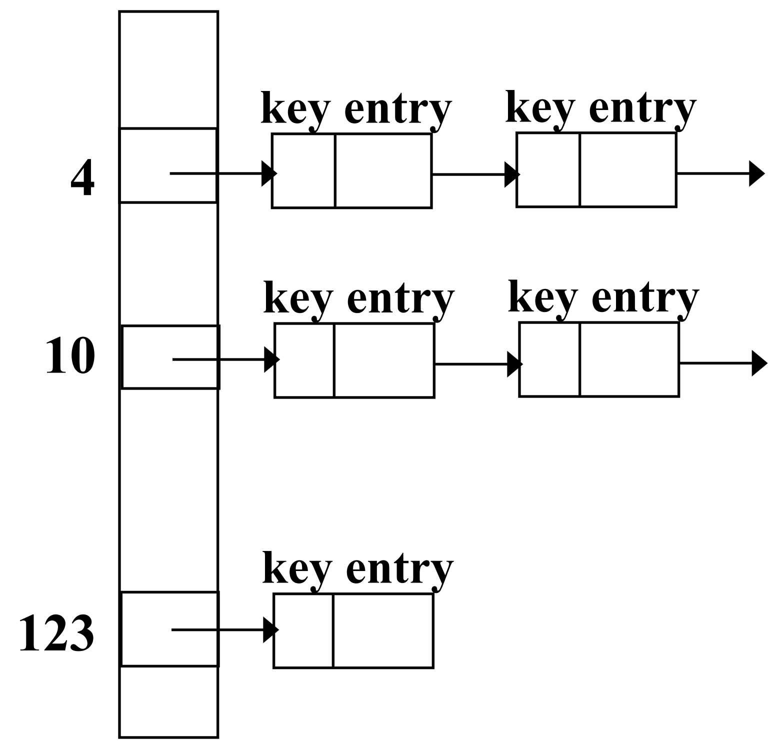
- **Linear probing:** increase by 1 each time
- **Quadratic probing:** to the original position, add 1, 4, 9, 16,...

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!



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Applications 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

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When are other representations more suitable 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