Searching, Maps, Tries (hashing)

- Searching is a fundamentally important operation
  - We want to search quickly, very very quickly
  - Consider searching using Google, ACES, issues?
  - In general we want to search in a collection for a key

- We've searched using trees and arrays
  - Tree implementation was quick: O(log n) worst/average?
  - Arrays: access is O(1), search is slower

- If we compare keys, log n is best for searching n elements
  - Lower bound is \( \Omega \log(n) \), provable
  - Hashing is O(1) on average, not a contradiction, why?
  - Tries are O(1) worst-case!! (ignoring length of key)

From Google to Maps

- If we wanted to write a search engine we’d need to access lots of pages and keep lots of data
  - Given a word, on what pages does it appear?
  - This is a map of words->web pages

- In general a map associates a key with a value
  - Look up the key in the map, get the value
  - Google: key is word/words, value is list of web pages
  - Anagram: key is string, value is words that are anagrams

- Interface issues
  - Lookup a key, return boolean: in map or value: associated with the key (what if key not in map?)
  - Insert a key/value pair into the map

Interface at work: MapDemo.java

```java
while (scanner.hasNext()) {
    String s = (String) scanner.next();
    Counter c = (Counter) map.get(s);
    if (c != null) c.increment();
    else map.put(s, new Counter());
}
```

- Key is a (Counter) map.get(s)
  - Interface in code below shows how Map class works

Accessing all values in a map (e.g., print)

- Access every key in the map, then get the corresponding value
  - Get an iterator of the set of keys: map.keySet().iterator()
  - For each key returned by this iterator call map.get(key) ...

- Get an iterator over (key,value) pairs, there's a nested class called Map.Entry that the iterator returns, accessing the key and the value separately is then possible
  - To see all the pairs use entrySet().iterator()
External Iterator without generics

- The Iterator interface accesses elements
  - Source of iterator makes a difference: cast required?

```java
Iterator it = map.keySet().iterator();
while (it.hasNext()){
    Object value = map.get(it.next());
}
```

```java
Iterator it2 = map.entrySet().iterator();
while (it2.hasNext()){
    Map.Entry me = (Map.Entry) it.next();
    Object value = me.getValue();
}
```

External Iterator with generics

- Avoid Object, we know what we have a map of
  - Is the syntax worth it?

```java
Iterator<String> it = map.keySet().iterator();
while (it.hasNext()){
    Object value = map.get(it.next());
}
```

```java
Iterator<Map.Entry<String,Counter>> it2 =
map.entrySet().iterator();
while (it2.hasNext()){
    Map.Entry<String,Counter> me = it.next();
    Object value = me.getValue();
}
```

Hashing: Log (10^{100}) is a big number

- Comparison based searches are too slow for lots of data
  - How many comparisons needed for a billion elements?
  - What if one billion web-pages indexed?

- Hashing is a search method: average case O(1) search
  - Worst case is very bad, but in practice hashing is good
  - Associate a number with every key, use the number to store the key
    - Like catalog in library, given book title, find the book
  - A hash function generates the number from the key
    - Goal: Efficient to calculate
    - Goal: Distributes keys evenly in hash table

- There will be collisions, two keys will hash to the same value
  - We must handle collisions, still have efficient search
  - What about birthday “paradox”: using birthday as hash function, will there be collisions in a room of 25 people?

- Several ways to handle collisions, in general array/vector used
  - Linear probing, look in next spot if not found
    - Hash to index h, try h+1, h+2, ..., wrap at end
    - Clustering problems, deletion problems, growing problems
  - Quadratic probing
    - Hash to index h, try h+1^2, h+2^2, h+3^2, ..., wrap at end
    - Fewer clustering problems
  - Double hashing
    - Hash to index h, with another hash function to j
    - Try h, h+j, h+2j, ...
Chaining with hashing

- With n buckets each bucket stores linked list
  - Compute hash value h, look up key in linked list table[h]
  - Hopefully linked lists are short, searching is fast
  - Unsuccessful searches often faster than successful
    - Empty linked lists searched more quickly than non-empty
  - Potential problems?

- Hash table details
  - Size of hash table should be a prime number
  - Keep load factor small: number of keys/size of table
  - On average, with reasonable load factor, search is O(1)
  - What if load factor gets too high? Rehash or other method

Hashing problems

- Linear probing, hash(x) = x, (mod tableszie)
  - Insert 24, 12, 45, 14, delete 24, insert 23 (where?)

- Same numbers, use quadratic probing (clustering better?)

What about chaining, what happens?

What about hash functions

- Hashing often done on strings, consider two alternatives

```java
public static int hash(String s) {
    int k, total = 0;
    for (k=0; k < s.length(); k++){
        total += s.charAt(k);
    }
    return total;
}
```

- Consider total += (k+1)*s.charAt(k), why might this be better?
  - Other functions used, always mod result by table size
- What about hashing other objects?
  - Need conversion of key to index, not always simple
  - Every object contains hashCode()!
Trie picture and code (see Trie.java)

- To add string
  - Start at root, for each char create node as needed, go down tree, mark last node

- To find string
  - Start at root, follow links
    - If null, not found
  - Check word flag at end

- To print all nodes
  - Visit every node, build string as nodes traversed

- What about union and intersection?

  Indicates word ends here