Introduction

This week we will be reviewing symbol tables, their implementations, and applications.

Symbol Tables

Symbol tables are ways of storing key, value pairs. We can think of them like a dictionary where the words are the keys and the definitions are the values. Like dictionaries, symbol tables allow us to easily find a given key and then its corresponding value. Symbol tables also support easy additions of new keys with their values.

There are two important things to remember about symbol tables in Java. First that they are usually unordered. This means that there is no guarantee about the order items will be drawn from the map using an iterator and that the order may change after using an iterator. Second that keys are unique. When we add a key-value pair to a symbol table, if the key was already present, the value is updated to the new value. If it was not present, the key is added with the given value.

Java Map

In Java, we can implement a symbol table using the built-in Map library. We must specify the types for the keys and values. Maps support the following operations:

- **put(key, value):** Adds a key-value pair to our Map.
- **get(key):** Returns the value associated with the given key or Null if not present
- **contains(key):** Returns a boolean corresponding to whether or not the given key is present in the Map.
- **iterator:** Returns an iterator over the keys in the Map

Implementation

A naive implementation of a symbol table is an array of keys where we iterate through to find the key we were looking for. This implementation clearly has an \(O(n)\) runtime for the get operation above where \(n\) is the number of keys in the symbol table. We can instead implement a symbol table using binary search to achieve faster runtimes. To do this we must make sure that the keys are all comparable we can then build two parallel arrays of keys and values such that the key array is sorted. We can then search the array using binary search to find if the given key if it exists.

With a binary search implementation, the run time of put is still \(O(n)\) as the array must be shifted for each addition. The runtime of get and contains however are both now \(O(log(n))\) since they are conducted using binary search of a sorted array.

Symbol Tables in Other Languages

In Java we implement symbol tables with the Map collection, a built-in library which nonetheless must be imported into our program. In other languages, there is special syntax specifically for symbol tables making them easy to instantiate and edit. Python for example uses "dictionaries" as its implementation of a symbol table. In Python, dictionaries are a primitive type like ints or lists (Python's term for arrays) and thus can be created as easily as these types can.
Practice Problems

**Problem 1.** You are given a stream of $n$ characters from a known alphabet of $k$ characters. Determine which characters appear exactly 5 times in the stream. Try to use $O(n \log k)$ time and $O(k)$ space

*Solution.* We build a symbol table of size $k$ which maps from characters to the frequency of times they have appeared. We first sort the list of characters and add them to our Map in the sorted order with initial frequency value of 0. Then, for each character we see in the stream, we increase it’s value by 1. After we have seen every letter in the stream, we iterate through the map to find which keys have appeared exactly 5 times.

Runtime: Sorting the $k$ characters takes $O(k \log k)$ time. Then when we add them each to the map they are in sorted order already. This take $k$ space. For each element we check if it is in the array and increase the characters frequency by 1. This takes $\log (k)$ time for each element. Iterating through the map takes $k$ time. Thus the total runtime is $O(k \log k + n \log (k) + k) = O(n \log (k))$.

**Problem 2.** Jesse is a history buff. He has memorized all the most important dates in the past $k$ years. He found there are exactly $n$ important dates. He wants his list of dates to be available online so that people can check if their birthdays were important dates. His website can’t run too slow though and needs you to build an algorithm to check if a date is important. Design an algorithm that does this in $O(\log (k))$.

*Solution.* We build a symbol table to represent all the dates. The keys of our symbol table are the years and the values are a list of all the important dates within that year. When we want to check if a date is important we first check if there is a key for it’s year it in our symbol table. If not we return False, if so we check if the corresponding date array includes the date we’re searching for.

Runtime: To check if a year is a key will take $\log (k)$ time since we can have at most $k$ keys in our symbol tables. The corresponding array can be at most 365 elements long (one for each day) thus the time to search this array is $O(365)$ or constant. So the total search time is $O(\log (k))$.