CS211, Lecture 19
Linear Search Structures

Announcements:

Overview:

- search structure reminder
- sorted arrays, sorted lists
- sets, sorted sets
- multisets/bags
- dictionary/map
- hashtables

1. Motivation

1.1 ADT Reminder

- ADT: data and operations
- interface gives functionality of ADT
- ADT uses variety of foundational structures

1.2 ADT Categories

- Search Structures
- Sequence Structures

1.3 Search Structures

- large collection of *ordered* data
- need to find something

1.4 Linear Search Structures

- arrays, lists, dictionaries, hashtables

1.5 Interface to implement

```
interface SearchStructure {
    void insert(Object o);
    void delete(Object o);
    boolean search(Object o);
    int size();
}
```


2. Sorted Arrays

2.1 Why sorted?

- linear search is O(n): OK
- binary search is O(log n): better!

2.2 Data

- items in array, current element, count

2.3 Operations

- search: if find item ***i***, return true; use binary search
- insert (allowing for repeats):
  - search for item to set cursor (where item should go)
  - make array bigger if more space needed (sadly, O(n))
  - move items higher than ***i*** to the right
  - insert item
- delete (for repeated values, O(n)):
  - find each occurrence of item ***i***
  - shuffle items to the left, overwriting item ***i***

2.4 More? Chap 7 in DS&A; 7.5 in DS&SD

2.5 Example

```
public class TestSortedArray {

    public static void main(String[] args) {
        SortedArray sa =
            new SortedArray(Integer.parseInt(args[0]));
        System.out.println(sa);
        sa.insert("A");
        System.out.println(sa);
        sa.insert("B");
        System.out.println(sa);
        sa.insert("B");
        System.out.println(sa);
        sa.insert("D");
        System.out.println(sa);
        sa.insert("A");
        System.out.println(sa);
        sa.insert("C");
        System.out.println(sa);
        System.out.println("SA size: " + sa.size());
    }
}
/* Sample session:
    > java TestSortedArray 3
    [null, null, null]
    [A, null, null]
    [A, B, null]
    [A, B, B]
    [A, B, B, D]
    [A, A, B, B, D]
    [A, A, B, B, C, D]
    SA size: 6
*/
```

```java
import java.util.Arrays;
class SortedArray implements SearchStructure {

    private Comparable[] a;
    private int size;   // max size of array
    private int cursor; // position to insert element
    private int count;  // current count of elements

    // constructor, getters, setters
    // more methods: isFull, isEmpty, size

    public void sort() { Arrays.sort(a); }

    public String toString() {
        return Arrays.asList(a).toString();
    }

    public boolean search(Object key) {
        int left = 0;
        int right = count - 1;
        int middle = 0;
        while (left <= right) {
            middle = (left + right)/2;
            int test = a[middle].compareTo(key);
            if (test < 0) left = middle+1;
            else if (test > 0) right = middle-1;
            else { cursor = middle; return true; }
        }
        // If we reach here, we didn't find key:
        cursor = right + 1;
        return false;
    }
```



```java
      public void insert(Object key) {
        search(key);
        int oldcount = count;
        count++;
        if (this.isFull()) {
            Comparable[] aNew = new Comparable[count];
            System.arraycopy(a,0,aNew,0,size);
            a = aNew;
            size = a.length;
        }
        for (int i = oldcount-1; i >= cursor; i--)
            a[i+1] = a[i];
        a[cursor] = (Comparable) key;
    }

    public void delete(Object key) {
        int same=0;
        for (int i = 0; i< size; i++)
            if (a[i].equals(key)) same++;
            if (same > 0) {
                int oldsize = size;
                ize = size - same;
                Comparable[] aNew = new Comparable[size];
            int newindex = 0;
                for (int i = 0; i < oldsize;i++) {
                    if (!a[i].equals(key))
                        aNew[newindex]=a[i];
                    newindex++;
                }
            }
        }
}
```


3. Lists for Searching

3.1 Sorted?

- no, not needed
- but we'll delete repeats this time

3.2 Data:

- head of list
- cursors for current and previous nodes

3.3 Operations:

- search: linear search (O(n))
  - starting at head, look at each element
  - set **`current`** and **`previous`** cursors during search
- insert:
  - check if **`item`** already exists
  - if not, make item the head of the list
- delete:
  - if not in list, return **`false`** (search sets cursors)
  - if in list and previous is **`null`**, remove **`head`**
  - else, connect the **`previous`** node to the **`current`**'s **`next`**


```java
public class TestSearchList {
    public static void main(String[] args) {
        SearchList s = new SearchList();
        s.insert(new Integer(5));
        s.insert(new Integer(1));
        s.insert(new Integer(2));
        s.insert(new Integer(5));
        System.out.println(s);
        s.delete(new Integer(5));
        System.out.println(s);
        System.out.println(s.size());
        System.out.println(s.search(new Integer(1)));
    }
}

/* Output:
    2 1 5
    2 1
    2
    tru e
*/

class SearchList implements SearchStructure{
    private ListNode head;
    private int size;
    private ListNode current;  // set during search
    private ListNode previous; // set during search

    // constructors, inner class, more methods
```

```
      public void insert(Object o) {
        if (!search(o)) {
            head = new ListNode(o,head);
        size = size + 1;
        }
    }

    public void delete(Object o) {
        if (!search(o))
            return;
        if (previous == null) {
            head = head.next;
        } else
            previous.next = current.next;
        size = size - 1;
    }

    public boolean search(Object o) {
        current = head;
      previous = null;
        while (current != null) {
            Comparable item = (Comparable)(current.item);
            if (item.compareTo(o) == 0)
                return true;
            else {
                previous = current;
                current = current.next;
            }
        }
        return false;
    }

} // Class SearchList
```


4. Sets

4.1 What's a *set*?

- unordered collection
- no repeats

4.2 ADT?

- searchable (insert, delete, contains, size, …)
- linear

4.3 Implementation?

- could use **`SearchList`** or modify **`SortedArray`**: be unsorted and not contain repeats, nulls
- see also DS&A, Chap 12

4.4 API

- constants: **`Collections.EMPTY_SET`**
- interfaces: **`Set`**, **`SortedSet`**
- abstract classes: **`AbstractSet`**
- concrete classes: **`BitSet`**, **`TreeSet`**, **`HashSet`**, **`LinkedHashSet`**

5. Multisets/Bags

5.1 Bag o' what?

- ***bag*** (or ***multiset***) is an unordered set with repeats
- so, think set with repeats

5.2 Why?

- shows up in **`Collections`** API: "Bags or multisets (unordered collections that may contain duplicate elements) should implement this interface directly."
- See DS&A, 12.3 (wrap an array)

5.3 Example

```
import java.util.*;
public class RemoveDups {
    public static void main(String[] args) {
        Collection fatlist = new LinkedList();
        for (int i=0; i<10; i++) fatlist.add("A");
        Collection leanlist = new HashSet(fatlist);
        System.out.println("Repeats: "+fatlist);
        System.out.println("No dups: "+leanlist);
    }
}

/* Output:
   Repeats: [A, A, A, A, A, A, A, A, A, A]
   No dups: [A]
*/
```

6. Dictionaries

6.1 Definitions

- big book with words and definitions
- modern approach: http://history.cc.ukans.edu/carrie/reference/dictionaries.html

6.2 Motivation by example (word search)

- Find meaning of *Muggle*
- Linear search: look up every word and compare
- Binary search: sort all the words and then compare
- how many words? lots! (http://hypertextbook.com/facts/2001/JohnnyLing.shtml)
- Big-Oh? Oh no…

6.3 Better process?

- quick way to find word means quick retrieval of definition
- use existing databases (books, online, files, …)
- inspect words? find letters? put words in certain locations? …
- possible to vastly improve lookup time

6.4 Improvements

- use array for constant time (O(1)) find and insert
- need way to convert word to integer for array pos
- example) consider first character of string?

6.5 Key-Value Pair

- more formal defs for "word" and "definition"
- ***Key***: symbol that labels information
- ***Value***: that information
- Operation: Find key in collection and retrieve value(s) associated with that key.
- example)
  Muggle is a word (a key) that has a definition (a value).

6.6 ADT Definition

- ***Dictionary***: From DADS, "An abstract data type storing items, or keys, associated with values. Basic operations are insert, find, and delete."
- related terms: ***map***, ***table***, ***look-up table***
- API uses `Map` (`Dictionary` is obsolete)

7. Hashtable

7.1 Definition of ***hashtable***:

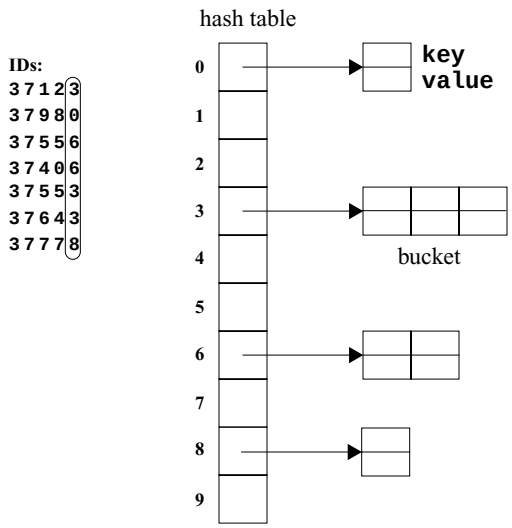
- Special kind of dictionary: "dictionary in which keys are mapped to array positions by a hash function…."
- process of building:
  - convert keys to integers
  - integers must be indicies of array
  - store keys in array using indicies
- needs:
  - function to convert object (key) to integer
  - array for indexing
  - elements of array to handle ***collisions*** (multiple keys hash to same index)

7.2 Collision

- Hash function plays "games" with objects to make integers…
- Having more than one key map to the same position is called a collision
- ***chained hashing***: use linked lists for each array element

7.3 Example

- want to store **`Student`** info (Student objects)
- use IDs as keys
- each key has values, like **`Student`** name
- need to insert keys by hashing (how?)



7.4 Rough Implementation of HashTable

```
abstract class MyHashTable implements SearchStructure {
    private LinkedList[] table; // array of buckets
    private int size;           // size of array

    // Create HashTable for input size:
    public MyHashTable(int size) {
        // create table
        // create lists in table
        // record size
    }

    // Return size of HashTable:
    public int size() { return size; }

    // Methods to implement:

    public void insert(Object key);
    // hash key to get bucket number
    // append key to list at that bucket

    public void delete(Object key);
    // hash key to get bucket number
    // walk list at that buck and remove ID

    public boolean search(Object key);
    // hash key to get bucket number
    // look for key by walking list at bucket

    public int hash(Object key);
    // convert key into an integer

}
```


7.5 “Complete” Implementation

```
import java.util.*;

class MyHashTable implements SearchStructure {
    private LinkedList[] table;
    private int size;
    public MyHashTable(int size) {
        table = new LinkedList[size];
        this.size = size;
        for (int row = 0; row < size; row++)
            table[row] = new LinkedList();
        }
    public int size() { return size; }
    public void insert(Object key) {
        table[hash(key)].add(key);
    }
    public void delete(Object key) {
        table[hash(key)].remove(key);
    }

    public boolean search(Object key) {
        return table[hash(key)].contains(key);
    }
    public int hash(Object key) {
        return (((Integer) key).intValue() % 10);
    }
    public String toString() {
        String s = "";
        for (int row = 0; row < size; row++)
            s += row+": "+table[row]+"\n";
        return s;
    }
}
```



```
public class FindName {

    public static void main(String[] args) {

        SearchStructure students = new MyHashTable(10);

        students.insert(new Integer(37123));
        students.insert(new Integer(37980));
        students.insert(new Integer(37556));
        students.insert(new Integer(37406));
        students.insert(new Integer(37553));
        students.insert(new Integer(37643));
        students.insert(new Integer(37778));

        System.out.print(students);

    }
}

/* Output:
    0: [37980]
    1: []
    2: []
    3: [37123, 37553, 37643]
    4: []
    5: []
    6: [37556, 37406]
    7: []
    8: [37778]
    9: []
*/
```

7.6 Storing Objects

- want to store objects to find corresponding values to keys
- **`Object`** supplies **`int hashCode()`**, which returns a hash code for the current object
- hash code usually related to an objects address (**`toString`** calls hash code…)
- for you to override (see wrapper classes for examples)
- must return same integer for same object
- equal objects (see **`equals`**) must return same hash code
- unequal objects may or may not return same hash code
- to store/retrieve object, call its **`hashCode`** method and use that integer to determine the bucket address

7.7 Hash Functions

- h(x) = x
- h(x) = x % 2
- h(x) = |x| mod <primenumber>
- and more …

7.8 Extremes

- Map each item to its own bucket, with no empty buckets
  - Zero collisions and no wasted space
  - perfect!
- Map all items to the same bucket, no empty buckets
  - Maximal collisions, single bucket
  - what have you gained by hashing in this way? essentially, linked-list
- Map all items to the same bucket, many empty buckets
  - Maximal collisions!
  - as bad as above *and* you're wasting space

7.9 Real Life

- some non-zero number of collisions
- some empty buckets
  - Collisions aren't always bad
  - Collisions are usually a tradeoff against wasted space.
- rules of thumb:
  - Reduce number of buckets:
    increase collisions, reduce space consumption
  - Increase number of buckets:
    reduce collisions, increase space consumption

7.10 Load Factor and Capacity

- ***Capacity***: number of buckets
- ***Load factor***: how full the hash table is allowed to get
- API: "When the number of entries in the hash table exceeds the product of the load factor and the current capacity, the capacity is roughly doubled by calling the rehash method."
- API: "As a general rule, the default load factor (.75) offers a good tradeoff between time and space costs."

7.11 API

- **`Hashtable`**
  - not synchronized
  - no **`null`**s
  - seems unpopular…
- **`HashMap`**
  - has **`Map`** operations
  - ordering not guaranteed
  - allows **`null`**
  - not synchronized
- **`HashSet`**
  - has **`Set`** properties
  - "uses" **`HashMap`** (extends?)
  - ordering not guaranteed
  - allows **`null`**
- **`LinkedHashMap`**, **`LinkedHashSet`**

8. API Example

```
import java.util.HashMap;
public class APIHashMap {
    private static String[] keys = {"A","B","C"};
    private static int[] vals = {1, 2, 3};
    private static HashMap stuff = new HashMap();
    public static void main(String[] args) {
        fillHashMap();
        showKeys();
        showValues();
        retrieveValues();
    }
    private static void fillHashMap() {
        for (int i=0 ; i < keys.length ; i++)
        stuff.put(keys[i],new Integer(vals[i])); }

    private static void showKeys() {
        System.out.println(stuff.keySet()); }

    private static void showValues() {
        System.out.println(stuff.values()); }

    private static void retrieveValues() {
        for (int i=0 ; i < keys.length ; i++)
        System.out.print(stuff.get(keys[i])+" ");
        System.out.println(); }
}
/* Output:
    [C, B, A]
    [3, 2, 1]
    1 2 3
*/
```


9. Exercises

- Rewrite **`TestSortedArray.java`** to remove repeated items.
- Rewrite **`TestSortedArray.java`** to use a ragged 2D array in which each row has a uniform maximum size. So, after the first row is filled, a new row is created, it becomes the second row, and new items are placed within it.
- Rewrite **`TestSortedList.java`** for a doubly-linked list.
- Rewrite (or extend or rewrite) **`FindName.java`** to return a student's name for its supplied ID. So, the IDs remain the keys, but you need to store key-value pairs inside the table, not just the keys. I suggest one of these options: giving up on implementing **`SearchStructure.java`** so you can have methods, like **`add(Object key, Object value)`**; or, using a **`Student`** object instead of **`key`** for insert/delete/search. You will still need to have a method to return the result of your search. Use **`Object`**'s **`hashCode`** for your hash function. Be sure to test your program with sample data.