Java Collection Framework: Maps and Sets

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Lists, revisited

- Lists are slow for searching
  - `indexOf`, `contains` are slow (O(n))
  - must potentially look at each element of list

```
public int indexOf(Object o) {
   for (int i = 0; i < size(); i++)
      if (get(i).equals(o))
        return i;
   return -1;
}
```

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A new collection type: Set

- **set**: an unordered collection with no duplicates
- main purpose of a set is to test objects for membership
- operations are exactly those for `Collection`

- interface `java.util.Set` has the following methods:

```
int size();
boolean isEmpty();
boolean contains(Object e);
boolean add(Object e);
boolean remove(Object e);
Iterator iterator();
```

```
boolean containsAll(Collection c);
boolean addAll(Collection c);
boolean removeAll(Collection c);
boolean retainAll(Collection c);
void clear();

Object[] toArray();
Object[] toArray(Object[] a);
```

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Set implementations in Java

- `Set` is an interface; you can't say `new Set()`

- There are two implementations:
  - `java.util.HashSet` is best for most purposes
  - we won't use the other one: `TreeSet`
  - Java's set implementations have been optimized so that it is very fast to search for elements in them
    - `contains` method runs in constant time! (How?!)

- Preferred: Set s = new HashSet();
  Not: HashSet s = new HashSet();

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Limitations of Sets

- Why are these methods missing from `Set`?
  - `get(int index)`
  - `add(int index, Object o)`
  - `remove(int index)`
- How do we access the elements of the set?
- How do we get a particular element out of the set, such as element 0 or element 7?
- What happens when we print a `Set`? Why does it print what it does?

Iterators for Sets

- A set has a method `iterator` to create an iterator over the elements in the set

- The iterator has the usual methods:
  - `boolean hasNext()`
  - `Object next()`
  - `void remove()`

Typical set operations

- Sometimes it is useful to compare sets:
  - **subset**: S1 is a subset of S2 if S2 contains every element from S1.

- Many times it is useful to combine sets in the following ways:
  - **union**: S1 union S2 contains all elements that are in S1 or S2.
  - **intersection**: S1 intersect S2 contains only the elements that are in *both* S1 and S2.
  - **difference**: S1 difference S2 contains the elements that are in S1 that are *not* in S2.

- How could we implement these operations using the methods in Java's Set interface?

How does a HashSet work?

- every object has a reasonably-unique associated number called a *hash code*
  - `public int hashCode()` in class `Object`
- `HashSet` stores its elements in an array `a` such that a given element `o` is stored at index `o.hashCode() % array.length`
  - any element in the set must be placed in one exact index of the array
  - searching for this element later, we just have to check that one place to see if it's there (O(1))
    - `"Tom Katz".hashCode() % 10 == 6`
    - `"Sarah Jones".hashCode() % 10 == 8`
    - `"Tony Balognie".hashCode() % 10 == 9`
- you don't need to understand this...

0	
1	
2	
3	
4	
5	
6	Tom Katz
7	
8	Sarah Jones
9	Tony Balognie

Membership testing in HashSets

- When testing whether a `HashSet` contains a given object:
  - Java computes the `hashCode` for the given object
  - looks in that index of the `HashSet`'s internal array
    - Java compares the given object with the object in the `HashSet`'s array using `equals;` if they are equal, returns `true`
- Hence, an object will be considered to be in the set only if *both*:
  - It has the same hash code as an element in the set, *and*
  - The equals comparison returns true
- an object that is put into a `HashSet` works best if it has a `public int hashCode()` method defined
  - `String, Integer, Double,` etc. have this already

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Set practice problems

- Modify our Sieve of Eratosthenes to return a `Set` of primes, instead of just printing them.

- Given a `List` of elements or string of many words, determine if it contains any duplicates, using a `Set`. (You can use a `Scanner` to break up a `String` by words.)

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Mapping between sets

- sometimes we want to create a mapping between elements of one set and another set
  - example: map people to their phone numbers
    - "Marty Stepp"   -->   "253-692-4540"
    - "Jenny"   -->   "253-867-5309"

- How would we do this with a list (or list(s))?
  - A list doesn't map people to phone numbers; it maps `ints` from 0 .. *size* - 1 to objects
  - Could we map some `int` to a person's name, and the same `int` to the person's phone number?
  - How would we find a phone number, given the person's name? Is this a good solution?

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A new collection: Map

- **map**: an unordered collection that associates a collection of element values with a set of keys so that elements they can be found very quickly (O(1)!)
  - Each key can appear at most once (no duplicate keys)
  - A key maps to at most one value
  - the main operations:
    - **put**(key, value)
      "Map this key to that value."
    - **get**(key)
      "What value, if any, does this key map to?"
  - maps are also called:
    - hashes or hash tables
    - dictionaries
    - associative arrays

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Java's Map interface

```
            public interface Map {
              Object put(Object key, Object value);
              Object get(Object key);
              Object remove(Object key);
Basic ops     boolean containsKey(Object key);
              boolean containsValue(Object value);
              int size();
              boolean isEmpty();

Bulk ops      void putAll(Map map);
              void clear();

Collection    Set keySet();
views         Collection values();
            }
```

Map implementations in Java

- `Map` is an interface; you can't say `new Map()`
- There are two implementations:
  - `java.util.HashMap` is best for most purposes
  - we won't use the other one: `TreeMap`

- Preferred: Map m = new HashMap();
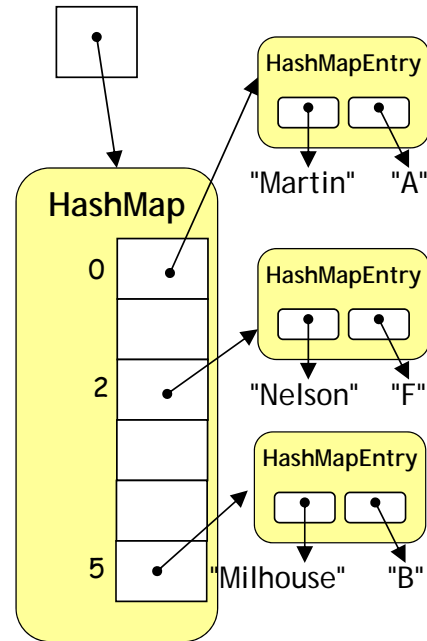 Not: HashMap m = new HashMap();

HashMap example

```
HashMap grades = new HashMap();
grades.put("Martin", "A");
grades.put("Nelson", "F");
grades.put("Milhouse", "B");

// What grade did they get?
System.out.println(
    grades.get("Nelson"));
System.out.println(
    grades.get("Martin"));

grades.put("Nelson", "W");
grades.remove("Martin");

System.out.println(
    grades.get("Nelson"));
System.out.println(
    grades.get("Martin"));
```


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Map example

```
public class Birthday {
    public static void main(String[] args){
        Map m = new HashMap();
        m.put("Newton", new Integer(1642));
        m.put("Darwin", new Integer(1809));
        System.out.println(m);
    }
}

Output:
{Darwin=1809, Newton=1642}
```

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Some Map methods in detail

- `public Object get(Object key)`
  - returns the value at the specified `key`, or `null` if the key is not in the map (constant time)

- `public boolean containsKey(Object key)`
  - returns `true` if the map contains a mapping for the specified key (constant time)

- `public boolean containsValue(Object val)`
  - returns `true` if the map contains the specified object as a value
  - this method is *not* constant-time O(1) … why not?

Collection views

- A map itself is not regarded as a collection
  - `Map` does not implement `Collection` interface
  - although, in theory, it could be seen as a collection of pairs, or a <u>relation</u> in discrete math terminology

- Instead collection *views* of a map may be obtained
  - Set of its keys
  - Collection of its values (not a set… why?)

Iterators and Maps

- `Map` interface has no iterator method; you can't get an Iterator directly

- must first call either
  - `keySet()`   returns a `Set` of all the keys in this `Map`
  - `values()`   returns a `Collection` of all the values in this `Map`

- then call `iterator()` on the key set or values
  - Examples:

    ```
    Iterator keyItr = grades.keySet().iterator();
    Iterator elementItr = grades.values().iterator();
    ```

  - If you really want the keys or element values in a more familiar collection such as an `ArrayList`, use the ArrayList constructor that takes a `Collection` as its argument

    ```
    ArrayList elements = new ArrayList(grades.values());
    ```

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Examining all elements

- Usually iterate by getting the set of keys, and iterating over that

```
Set keys = m.keySet();
Iterator itr = keys.iterator();
while (itr.hasNext()) {
    Object key = itr.next();
    System.out.println(key + "=>" +
                        m.get(key));
}

Output:
Darwin => 1809
Newton => 1642
```

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Map practice problems

- Write code to invert a `Map`; that is, to make the values the keys and make the keys the values.

```
Map byName = new HashMap();
byName.put("Darwin", "748-2797");
byName.put("Newton", "748-9901");

Map byPhone = new HashMap();
// ... your code here!
System.out.println(byPhone);

Output:
{748-2797=Darwin, 748-9901=Newton}
```
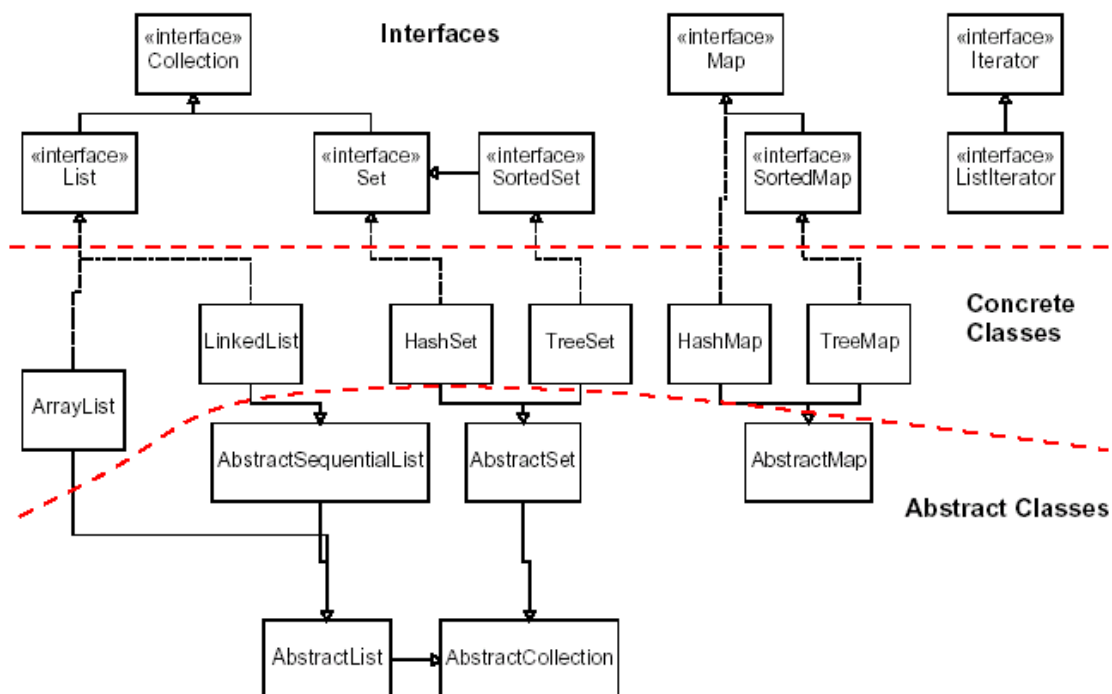
- Write a program to count words in a text file, using a hash map to store the number of occurrences of each word.

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Java Collections Framework

Compound collections

- Collections can be nested to represent more complex data
- example: A person can have one or many phone numbers
    - want to be able to quickly find all of a person's phone numbers, given their name
- implement this example as a HashMap of Lists
    - keys are Strings (names)
    - values are Lists (e.g ArrayList) of Strings, where each String is one phone number
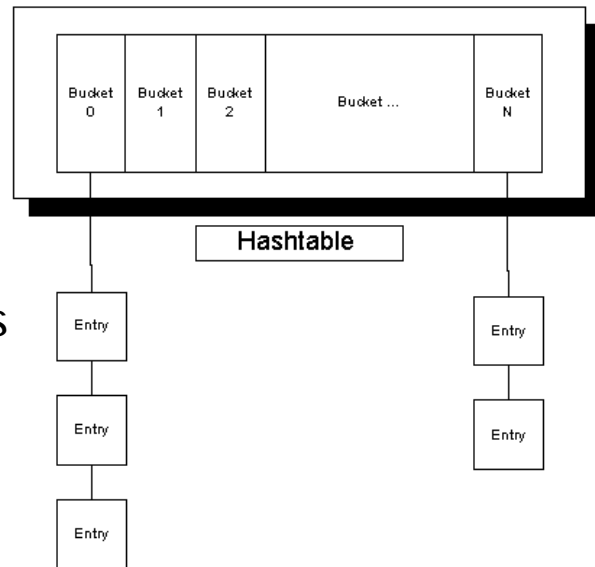
Compound collection code 1

```
// map names to list of phone numbers
Map m = new HashMap();
m.put("Marty", new ArrayList());
...
ArrayList list = m.get("Marty");
list.add("253-692-4540");
...
list = m.get("Marty");
list.add("206-949-0504");
System.out.println(list);


[253-692-4540, 206-949-0504]
```

Compound collection code 2

```
// map names to set of friends
Map m = new HashMap();
m.put("Marty", new HashSet());
...
Set set = m.get("Marty");
set.add("James");
...
set = m.get("Marty");
set.add("Mike");
System.out.println(set);
if (set.contains("James"))
  System.out.println("James is my friend");

{Mike, James}
James is my friend
```

References

- Koffman/Wolfgang Ch. 9, pp. 453-464

- *The Java Tutorial: Collections.*
  http://java.sun.com/docs/books/tutorial/
  collections/index.html

- *JavaCaps Online Tutorial: java.util package.*
  http://www.javacaps.com/scjp_util.html