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Bag Implementation

Our implementation of generic uses a HashMap as a representant, with the constraints that the values in the map can only be positive integers. The abstraction function transforms the representant into a multiset where the multiplicity of each element is the corresponding value in the HashMap. Note that we interpreted cardinality as the total number of elements (potentially duplicated) in the bag.

```
public class Bag<E> {

   // rep: map each object to the count of that object in this
   // rep-inv:  range of map contains only positive integers
   // Example:  A bag of 2 cats and a dog is map = { cat=2, dog=1 }

   private Map<E, Integer> map;

   public boolean repOK(){
      for(Integer count: map.values()){
         if (count <= 0 ) return false;
      }
      return true;
   }

   public Bag() {
      map = new HashMap<E, Integer>();
   }

   // add 1 occurrence of e to this
   public void insert(E e) {
      if(isIn(e)) {
         int counterForE = map.get(e);
         map.replace(e, ++counterForE);
      }
      else{
         map.put(e, 1);
      }
   }

   // remove 1 occurrence of e from this
   public void remove(E e) {
      int countItem = map.get(e);
      if (countItem == 1) {
        map.remove(e);
     }
      else{
        map.replace(e, countItem -1);
     }
   }
```

```java
    // return true iff e is in this
    public boolean isIn(E e) {
        return map.containsKey(e);
    }

    // return cardinality of this
    public int size() {
        int counter = 0;
        for(Integer count: map.values()){
            counter += count;
        }
        return counter;
    }

    // if this is empty throw ISE
    // else return arbitrary element of this
    public E choose() {
        if (map.size() == 0) throw new IllegalStateException("Bag.choose");
        Object keys[]= map.keySet().toArray();
        return (E) keys[0];
    }

    // conveniently, the <E,Integer> map is exactly the abstract state
    public String toString() { return map.toString(); }

}
```

Comparison of Abstract function (AF) and rep-inv between Bag and LiskovGenericSet (LGS):

AF of LGS maps an item at most once.

AF(c_LGS) = c_LGS[0], c_LGS[1], … … … c_LGS[n-1]

where n is the number of items in the set.

Rep-inv:

if n==0, c_LGS is empty and

if n>0, c_LGS[i] != c_LGS[j] where (i != j) and (0<=i,j<n) and

c_LGS.isIn(e) follows by c_LGS.insert(e) returns always true and

c_LGS.isIn(e) follows by c_LGS.remove(e) returns always false

where e is an item.

AF of Bag maps an items multiple times and keeps track of how many times an item is in the bag.

AF(c_bag) = c_bag[0], c_bag[1], … … … c_bag[n-1]

where c_bag[i] = (itemKey, count)

where 0<=i<n and

n is the number of unique items in the bag and count indicates how many times itemKey is in the bag

Rep-inv:

if n==0, c_bag is empty and

if n>0, c_bag[i].itemKey != c_bag[j].itemKey where (i != j) and (0<=i,j<n) and

c_bag.isIn(e) follows by c_bag .insert(e) returns always true and

c_bag[i].count > 0

where e is an item

Properties of LiskovGenericSet (LGS):

A generic Set is a mutable set of elements E with size equal or greater than 0 and no duplicates elements. Because there are no duplicates in Sets, if a Set contains an object and the object is removed, the Set will not contain the object. We wrote a JUnit theory to test this property for Sets – *remove()* followed by *isIn()* should always return false for Sets.

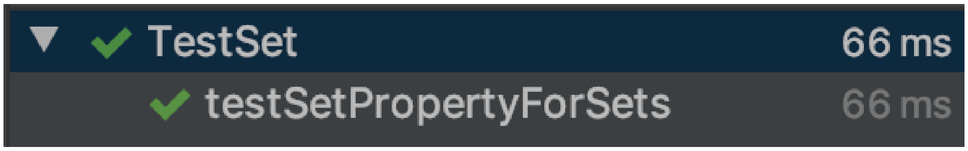
```
@DataPoints
public static int[] counts = { 2, 100, 50, 23 };
@DataPoints
public static Object[] objects = { "string", 1, new Object() };

// Property - Sets do not contain duplicates
// Theory - Regardless how many times an object is inserted into a Set,
//         when the same object is removed, it will not be present in the Set
@Theory
public void testSetPropertyForSets(Object object, int count) {
  LiskovGenericSet<Object> set = new LiskovGenericSet();
  assumeNotNull(object);


  // Fill Set with arbitrary count of object
  for (int i = 0; i < count; i++) {
    set.insert(object);
  }
  assumeTrue(set.isIn(object));

  set.remove(object);
  assertFalse(set.isIn(object));
}
```

To our expectation, this theory passed for Sets of any Object type and also regardless of how many times an object was added to the set – the object was always no longer an element of the Set after calling *remove()*.



```
▼ ✓ TestSet                          66 ms
      ✓ testSetPropertyForSets       66 ms
```

Is Bag a legitimate subtype of LiskovGenericSet (LGS)?

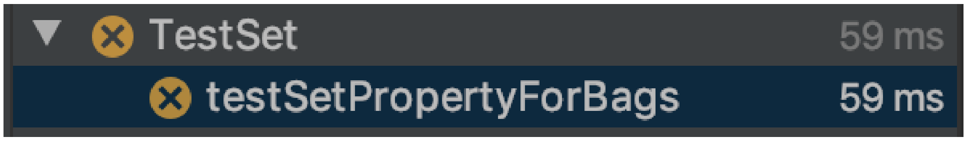
If Bags are subtypes of Sets they must adhere to the same properties as Sets as well – meaning Bags cannot contain duplicates. To test this, we applied the same Set property test to Bags.

```
// Property - Sets do not contain duplicates
// If Bags are subtypes of Sets then they must pass this property test
@Theory
public void testSetPropertyForBags(Object object, int count) {
   Bag<Object> bag = new Bag<Object>();
   assumeNotNull(object);

   // Fill Bag with arbitrary count of object
   for (int i = 0; i < count; i++) {
      bag.insert(object);
   }
   assumeTrue(bag.isIn(object));

   bag.remove(object);
   assertFalse(bag.isIn(object));
}
```

This theory failed for Bag – if an element was inserted multiple times into a Bag it would still be present in the Bag after *remove(),* therefore Bag can contain duplicates. Because it fails the Set property test, it is not possible for Bag to be a valid subtype of Set based on the Property rule.



```
▼ ☒ TestSet                        59 ms
      ☒ testSetPropertyForBags     59 ms
```

Properties of Bag:

A generic bag is a mutable multiset whose cardinality increases by one at each insertion and decreases by one at each removal. The size of a bag must equal or greater than 0.

To test this property, we wrote JUnit test that test whether cardinality gets incremented by one after inserting any element.

```
@Theory
public void testBagPropertyForBags(Object object, int count) {
   assumeNotNull(object);

   Bag<Object> bag = new Bag<Object>();

   // Fill Set with arbitrary count of object

   for (int i = 0; i < count; i++) {
      bag.insert(object);
   }

   int size = bag.size();
   bag.insert(objects);
   assertTrue(bag.size() == size + 1);

}
```

The test passes for Bag.

Is LiskovGenericSet (LGS) a legitimate subtype of Bag?

LiskovGenericSet violates the Bag property because after insertion of an element that is already in the LiskovGenericSet, the cardinality is not increased by one. Therefore, LiskovGenericSet is not a subtype of Bag. It is a violation of an evolution property. We can write a JUnit theory:

```
@Theory
public void testBagPropertyForSets(Object object, int count) {
   LiskovGenericSet<Object> set = new LiskovGenericSet<>();
   assumeNotNull(object);

   // Fill Bag with arbitrary count of object
   for (int i = 0; i < count; i++) {
      set.insert(object);
   }

   assumeTrue(set.isIn(object));
   int size = set.size();
   set.insert(object);
   assertEquals(set.size(), size + 1);
}
```

The test fails for LiskovGenericSet.

Contributions: We first came over our own solutions. Then we discussed over the cardinality of the bag, Bag properties, Set properties and Junit theories. The story combines Xavier’s Bag implementation, Anowarul’s rep-inv and AF comparison and Clayton’s Junit theories. Finally, we answered two questions whether Bag is a legitimate subtype of LiskovGenericSet or vice versa.