Solutions to Quiz 2 (December 4, 2017)

This quiz uses the same abstract data type as Quiz 1: a shopping list is an ordered list of unique items together with a positive integer quantity for each listed item (we will not consider units for quantities, e.g. 1 oz. vs. 1 lb. vs. 1 box, just a number).

For example, someone who plans to buy a gallon of milk, a small bunch of bananas, and a box of Klondike bars, might have this shopping list:

- 1% milk (1)
- Banana (3)
- Klondike bars (1)

Shopping lists are ordered, so the following is a different shopping list. It has the same items and quantities, but in a different order:

- Banana (3)
- Klondike bars (1)
- 1% milk (1)

This is not a shopping list:

- Banana (1)
- Banana (1)
- Banana (1)
- Klondike bars (1)
- 1% milk (1)

And neither is this:

- 1% milk (0)

An unlisted item has zero quantity, so the quantity of Oranges on every list on this page is 0.

Problem 1 (Recursive data types) (15 points).

The problems of this exam refer to the code for ShoppingList on page 6, which you may detach.

(a) Write the data type definition for ShoppingList.

Solution. ShoppingList = Empty() + AnotherItem(item:String, list:ShoppingList)

(b) Here is a new operation proposed for the ShoppingList type.

\[
\text{atMost}: \text{ShoppingList} \times \text{String} \times \text{int} \rightarrow \text{ShoppingList}
\]

requires true
effects returns a shopping list identical to list, except that anItem’s quantity on the returned list is the smaller of count and its quantity on list, i.e.
returnedList.howMany(anItem) == min(count, list.howMany(anItem))

Change just the precondition of this specification, as little as possible, so that the postcondition can always be satisfied:

Solution. requires count ≥ 0

Circle whether your new specification is STRONGER or WEAKER than the original specification, and explain why in one sentence:

Solution. spec is WEAKER because: (any of these answers is good)

• precondition is stronger
• the client has more restrictions
• any implementation that satisfies the original spec also satisfies the new spec
• the new spec allows at least one implementation, while the original spec’s legal implementations were the empty set, so the implementations of the new spec is a superset of the implementations of the original spec

Problem 2 (Recursive data types) (23 points).
Using your revised spec for atMost, fill in the blanks below to implement the new operation as an instance method of ShoppingList. Assume the other code in those classes remains unchanged.

public interface ShoppingList {
    ...
    /** assume specification comment is here, don’t write it */

Solution. public ShoppingList atMost(String anItem, int count);
}

class Empty implements ShoppingList {
    ...
    @Override public /* assume method signature is here, don’t write it */ {

Solution. return this;
or
return new Empty();
or
return ShoppingList.empty();
or
return empty();
}
Solution. This is approach A:

if (count == 0) return this.list.atMost(anItem, 0);
else return new AnotherItem(this.item, this.list.atMost(anItem, count-1));

This is approach B:

if (this.howMany(anItem) <= count) return this;
else return this.list.atMost(anItem, count);

Approach A removes the final occurrence(s) of anItem on the list, while approach B removes the initial occurrence(s). Removing initial or final occurrences may change the item's position on the abstract ordered list, which the spec for atMost did not allow. But that requires knowing the abstraction function for ShoppingList, which was omitted from the provided code, so both approaches were accepted for full credit.

An iterative solution using items() does not receive full credit because the unordered Set it returns clearly discards the ordering of the ShoppingList, so the order of the resulting list can never be guaranteed to match the order of the original list, contrary to the spec for atMost.

Problem 3 (Thread safety) (25 points).
This problem refers to the code for goShopping() on page 7, which you may detach.

For each of these comments about the thread safety of the code below, circle AGREE or DISAGREE and explain why in one sentence.

(a) The i variable is threadsafe because it is confined.

Solution. AGREE, because i is a local variable whose scope is the for loop, so no other thread has access to it.

(b) The itemLocations map is threadsafe because goShopping doesn't call any of its mutators.
Solution. DISAGREE, because: (any of these answers is good)

- the map could have beneficent mutation that happens when an observer is called
- other threads calling other operations of ‘Store’ could call mutators of the map

(c) The shoppers list is threadsafe because it uses threadsafe data types.

Solution. DISAGREE, because ArrayList is *not* a threadsafe datatype. It happens that shoppers is only accessed by the original thread that called goShopping(), but it is still in scope for the new threads, so it is not actually confined, and the potential for a bug exists.

(d) The code shown has a race condition.

Solution. AGREE, because multiple threads may see aisle.howMany(item) > 0 but then aren’t all able to aisle.remove(item).
(The threads started by goShopping() will not race in this way, because each thread is shopping for a different item, but multiple clients calling goShopping() can.)

(e) Declaring goShopping() with public synchronized would make goShopping() threadsafe.

Solution. DISAGREE. The synchronized keyword will solve the race condition between multiple clients calling goShopping(), but it will not prevent the threads created internally by goShopping() from using its rep unsafely.

Problem 4 (Map-filter-reduce) (22 points).

Let’s define map and filter operations for ShoppingList that examine and operate on the items (but not their quantities). For example, map could be used to replace Milk with 1% Milk, and filter could be used to filter to only the vegetarian items on the shopping list.
(a) Write mathematical type signatures (not Java method declarations) for the map and filter operations of ShoppingList. One argument of each operation should be a function, and all types should be specific to the shopping list problem, not generic type variables like <E> or <T>.

map: \( x \rightarrow \)

filter: \( x \rightarrow \)

Solution.

One possible answer:
map: ShoppingList \( \times \) (String \( \rightarrow \) String) \( \rightarrow \) ShoppingList
filter: ShoppingList \( \times \) (String \( \rightarrow \) boolean) \( \rightarrow \) ShoppingList

Another answer using Java’s functional interfaces:
map: ShoppingList \( \times \) Function<String,String> \( \rightarrow \) ShoppingList
filter: ShoppingList \( \times \) Predicate<String> \( \rightarrow \) ShoppingList
(b) Assuming that map and filter are now implemented as instance methods of ShoppingList, write Java code to convert the list input:

- small apples (5)
- green apples (3)
- leafy lettuce (1)
- yucky meat (3)
- yummy meat (7)

into the list output:

- apples (8)
- lettuce (1)
- meat (7)

Use the fewest Java expressions you can.

ShoppingList input = ...; // abstract value shown above

ShoppingList output =

Solution.

input.filter( item -> !item.equals("yucky meat") )
    .map( item -> item.substring(6) );

Syntactic variations on the lambda expression are possible, as are function bodies with equivalent behavior on these particular items, e.g. !item.contains("yucky") or item.split(" ")[1].

Problem 5 (Grammars) (15 points).

(a) Complete this partial grammar so that it can recognize shopping lists. It should match as many valid shopping lists as possible, and exclude as many invalid lists as possible. For example, the grammar should match:

- Milk (1)
- Banana (30)
- Klondike bars (1)

but not match:

- Milk (0)

Here is the partial grammar, with root nonterminal list. Complete the grammar by adding new rules; don’t change existing rules.

list ::= ('• ' item ' ' quantity '
')*;
item ::= [A-Za-z ]*;

Solution. quantity ::= '(' [1-9] [0-9]* ')';
(b) Read the grammar carefully, and then write Java code below to construct a ShoppingList that this grammar cannot match. (If you can’t think of one, say that, but also write Java code that constructs some ShoppingList.)

ShoppingList list =

**Solution.** Any answer with non-letter/non-space characters in an item name is unparseable by the grammar, e.g.:

```
empty().another("1% milk");
```

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```java
/** Immutable shopping list. */
public interface ShoppingList {

  /** @return an empty shopping list */
  public static ShoppingList empty() {
    return new Empty();
  }

  /** @return this list with 1 instance of item added */
  public ShoppingList another(String item);

  /** @return the items on this list */
  public Set<String> items();

  /** @return the quantity of item on this list, >= 0 */
  public int howMany(String item);

  //...
}

class Empty implements ShoppingList {
  public Empty() {
  }

  // ...
}

class AnotherItem implements ShoppingList {
  private final String item;
  private final ShoppingList list;

  public AnotherItem(String item, ShoppingList list) {
    this.item = item;
    this.list = list;
  }

  // ...
}
```
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```java
/** Aisle is a threadsafe mutable data type representing an aisle in a store */
public class Aisle { ... }

/** ShoppingCart is a threadsafe mutable data type representing a shopping cart */
public class ShoppingCart { ... }

public class Store {

    private final Map<String,Aisle> itemLocations;
    ... // other fields and operations

    /**
     * Requires that this store has sufficient quantity of every item on list.
     * Modifies the cart and this store to move the quantity of each item on list
     * from the store to the cart.
     */
    public void goShopping(final ShoppingList list, final ShoppingCart cart) {
        final List<Thread> shoppers = new ArrayList<>();
        for (final String item: list.items()) {
            Thread shopper = new Thread(() -> {
                Aisle aisle = itemLocations.get(item);
                for (int i = 0; i < list.howMany(item); ++i) {
                    if (aisle.howMany(item) > 0) {
                        cart.add(item);
                        aisle.remove(item);
                    }
                }
            });
            shopper.start();
            shoppers.add(shopper);
        }
        for (Thread shopper : shoppers) { shopper.join(); }
    }
}
```