Com S 228 Fall 2016

Project 3: Doubly-Sorted List (250 pts)

Due at **11:59pm**

Friday, Oct 28

1. List Structure

In this project, you are asked to implement a sorted linked list structure to help a fruit store update its inventory. To simplify this task, we make the following assumptions:

a) *The store sells fruits **by unit** (e.g., an apple, a bunch of grapes, etc.) not by weight.*
b) *Every type of fruit, regardless of its quantity on stock, is displayed in **exactly one** storage bin.*
c) *Storage bins are numbered consecutively starting at 1, and as many bins as needed are available.*
d) *The names of fruits from the input or passed as arguments to method calls will **always** be from the list given in Appendix A. (These names are in lower case English letters.)*

A doubly-sorted list (DSL) consists of two doubly-linked lists (DLLs), which share the same set of nodes, and are **sorted** respectively by two different data fields. In the DSL, exactly one node N is created for every type of fruit currently on stock. Shown in the top row of Fig. 1, such a node has three data fields: `fruit`, `quantity`, and `bin`, which respectively store the name of the fruit (as a String object), its quantity in units, and the number of its storage bin. At the bottom of the figure displays two nodes with actual data values. They record 50 apples stored in bin 5, and 100 bunches of grapes in bin 8.

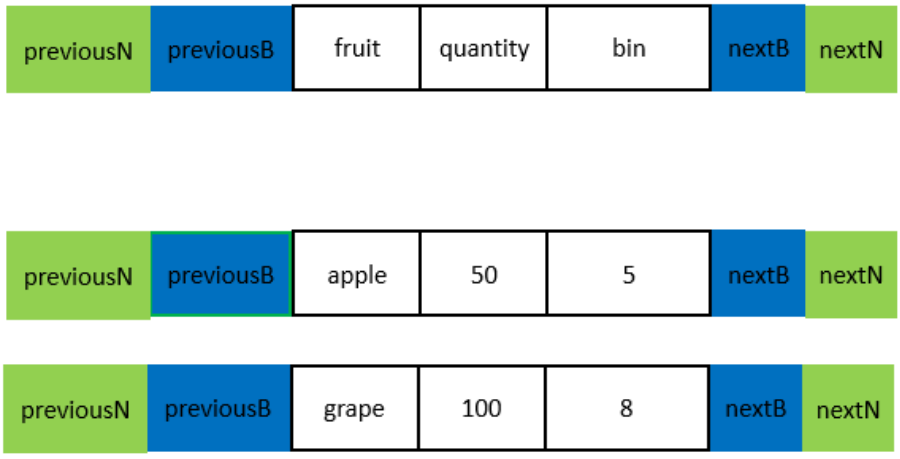


Fig. 1. A node has three data fields and two pairs of links. The bottom two nodes have their data fields filled with values.

In addition to the three data fields, a node N also has two pairs of links: `nextN` and `previousN`, and `nextB` and `previousB`. The first pair locates the two nodes created for the fruits whose names immediately precede and succeed, in the alphabetical order, the name N`.fruit` of the

fruit represented by N. All the `nextN` and `previousN` links thus form a doubly-linked list (DLL) which orders the nodes by fruit name. The list, referred to as the ***N-list***, is accessed via a dummy node `headN`. Fig. 2 shows an N-list for four different types of fruits. Note that the last node ("pear") has its `nextN` link reference the dummy node `headN`.

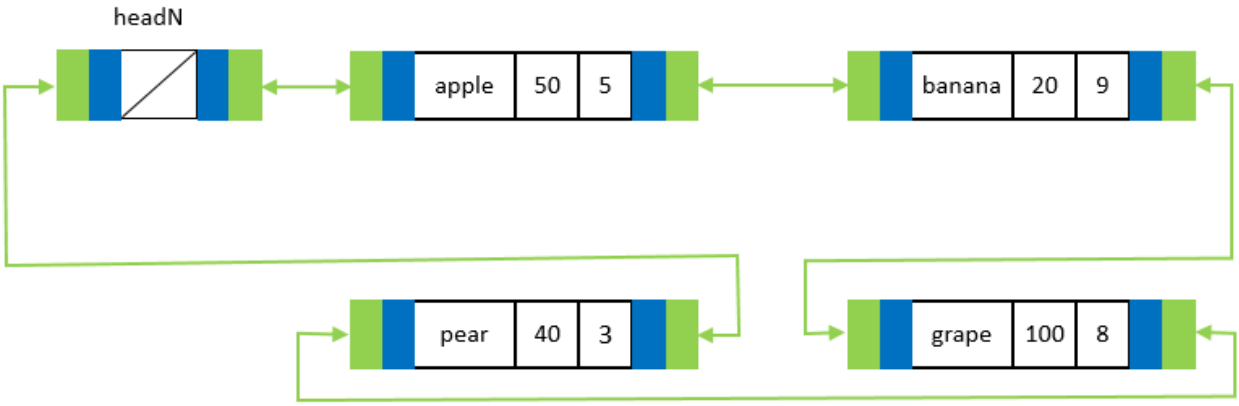


Fig. 2. N-list ordered by fruit name. Every pair of `nextN` and `previousN` links is represented by a double-headed arrow.

At the node N, the other two links `nextB` and `previousB` respectively reference the nodes for the fruits stored in the previous and next **non-empty** bins in the numerical order. For instance, suppose N references the "apple" node in Fig. 2. As the node shows, all apples are displayed in bin 5 at the fruit store. The last non-empty bin is bin 3, which stores pears, so the link N.`previousB` references the "pear" node. Meanwhile, the next non-empty bin is bin 8. Therefore, N.`nextB` references the "grape" node. All the `nextB` and `previousB links` induce a second DLL sorted by bin number. It is called the ***B-list*** accessed via a dummy node `headB`. Fig. 3 displays the B-list formed by the same four nodes from Fig. 2.

To distinguish between the N- and B-lists, all the `nextN` and `previousN` links will be colored green as in Fig. 2, while all the `nextB` and `previousB links` will be colored blue as in Fig. 3. The DSL is now displayed compactly in Fig. 4 by simply merging the two DLLs from Figs. 2 and 3.

When all fruits have been sold out or disposed, the DSL has empty N- and B-lists. The following two conjunctions are true:

```
headN.nextN == headN && headN.previouN == headN
headB.nextB == headB && headB.previouB == headB
```

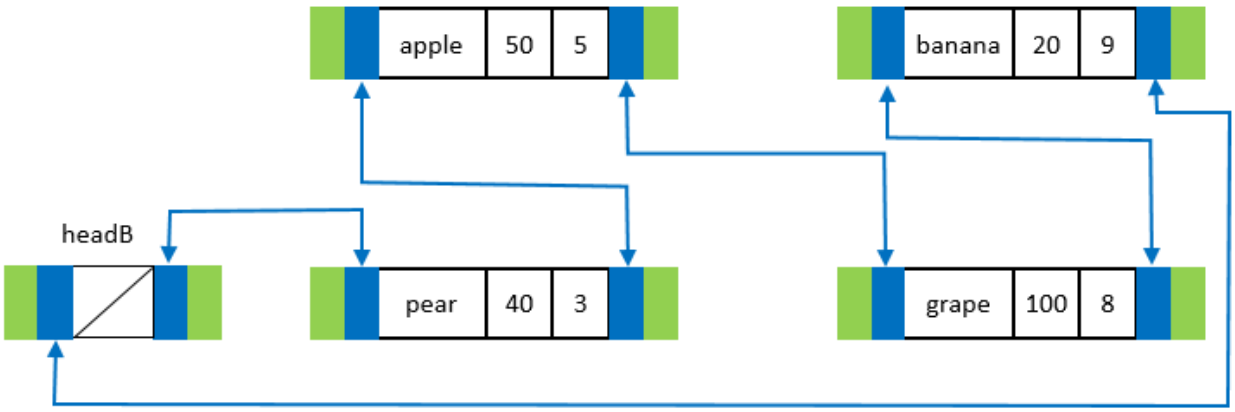


Fig. 3. B-list linking the same four nodes from Fig. 2.

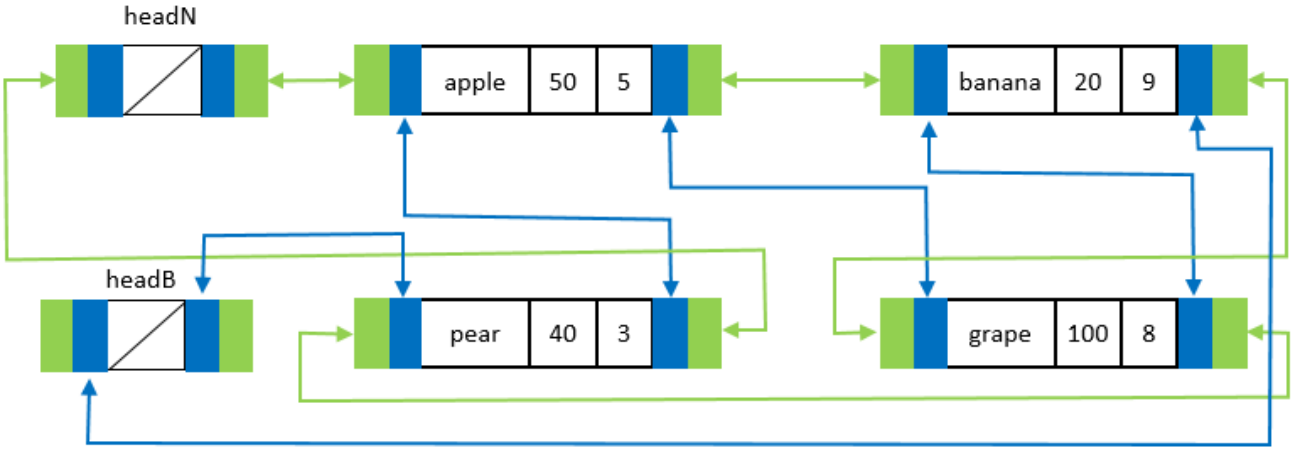


Fig. 4. Doubly-sorted list merging the N- and B-lists
from Figs. 2 and 3.

2. Constructors

There are three constructors:

```
public DoublySortedList()
public DoublySortedList(String inventoryFile) throws FileNotFoundException
public DoublySortedList(int size, Node headN, Node headB)
```

The first one is a default constructor which initializes an empty DSL. Fruits will be added to the list later using addition methods introduced later. The second constructor builds a DSL over an inventory file, of which an example is given below:

```
pear      40      3
apple     50      5
banana    20      9
grape     100     8
```

An input inventory file is assumed to always meet the following format requirements such that there is **no need** to check for correctness of formatting:

e) Fruits are listed on consecutive lines.
f) Each line displays the name of a different fruit, its quantity, and the number of its storage bin, with at least one blank or tab in between.

As in the earlier example, the fruits on an inventory list may not be in the alphabetical order. In the first stage of construction, you are asked to scan the list and create a node over every scanned line. The node's two pairs of links (`nextN`, `previousN`) and (`nextB`, `previousB`) are initialized to represent the order of the scan. The links `headN` and `headB` both reference the first created node. The scan creates two DLLs, neither of which is sorted at the moment.

In the second stage, an **insertion sort** is carried out on each DLL by the following method:

```
public void insertionSort(boolean sortNList, Comparator<Node> comp)
```

Two comparator classes, `NameComparator` and `BinComparator`, are provided for the insertion sorts by name and by bin number to construct the N- and the B-lists, respectively. Please note that sorting here is performed on the nodes. You **cannot** first put the fruit names or their bins in an array and then sort the array instead.

The third constructor has been implemented. It will be used for splitting a DSL into two (to be described in Section 6) and by the TA for testing.

3. Stocking Fruits

The list is updated whenever new fruits are stocked. Every new fruit type leads to the creation of a node. For compactness of display, all fruits of this type should be placed into the **first** empty bin by number.

3.1 Insertion

Addition of a fruit in some specified quantity is carried out by the following method:

```
public void add(String fruit, int n) throws IllegalArgumentException
```

It starts out with a sequential search in the N-list for `fruit`. Two possible situations may arise:

1) The search finds a node N housing `fruit`, simply increase the N`.quantity` field by `n`. This is illustrated in Fig. 5 below.

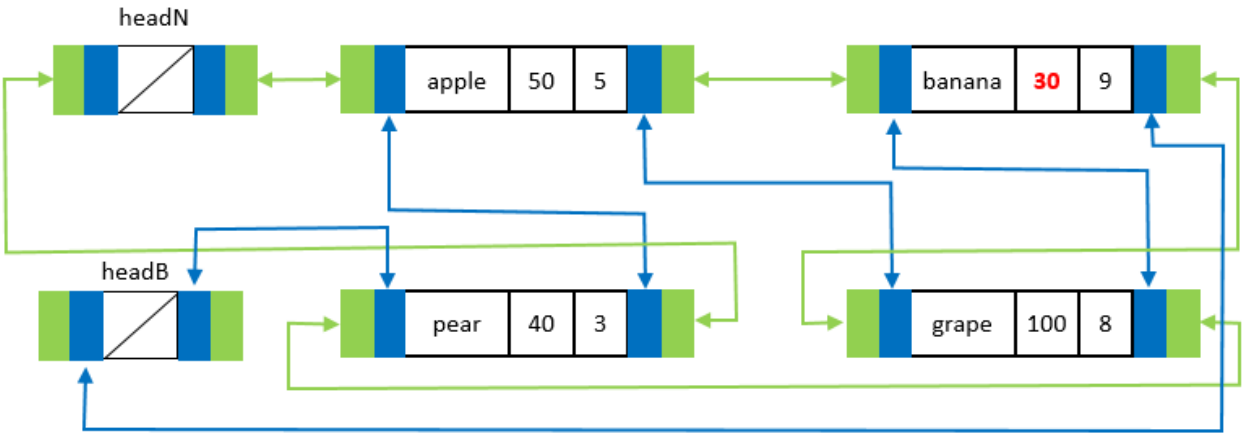
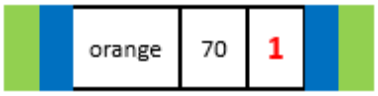


Fig. 5. Execution of `add("banana", 10)` on the DSL in Fig. 4. The changed value of the `quantity` field in the "banana" node is colored red.

2) If no node for `fruit` is found after the search, the fruit is new on the stock. In this case, a new node is created to store the fruit in the first available bin. To illustrate, suppose that `add("orange", 70)` is executed on the DSL in Fig. 4. A search of the B-list finds the first empty bin to be bin 1. Create the following node (in which the bin number is shown in red).



Next, add the node to the N-list and the B-list by calling two helper methods: `insertN()` and `insertB()`. The first method determines the "orange" node to be between the "grape" and "pear" nodes, while the second method determines that it should appear right after `headB` on the B-list. In Fig. 6, the two links to be removed are marked with red crosses. Fig. 7 displays the DSL after addition of the new node (which is now referenced by `headB`).

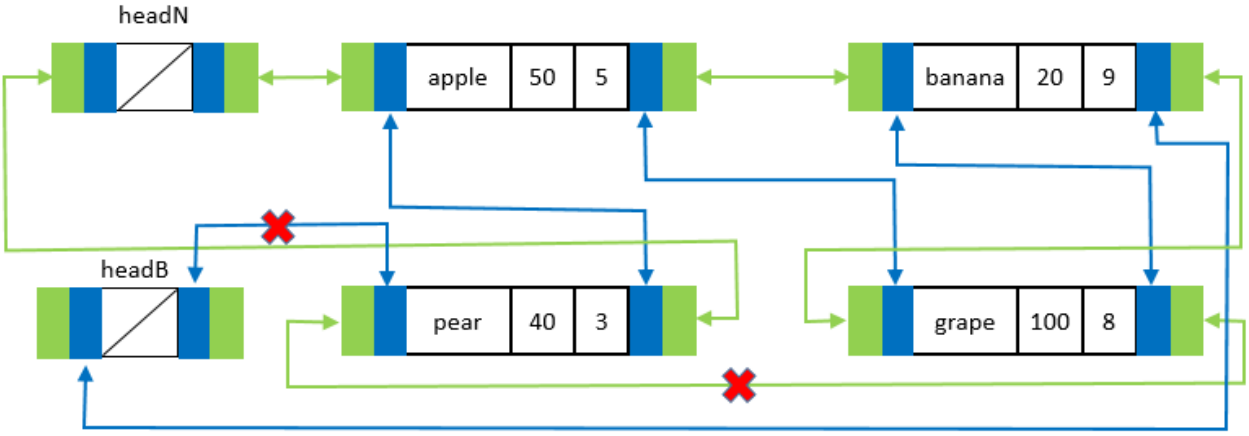


Fig. 6. Links marked by crosses are to be deleted during a call `add("orange", 70)` on the DSL in Fig. 4.

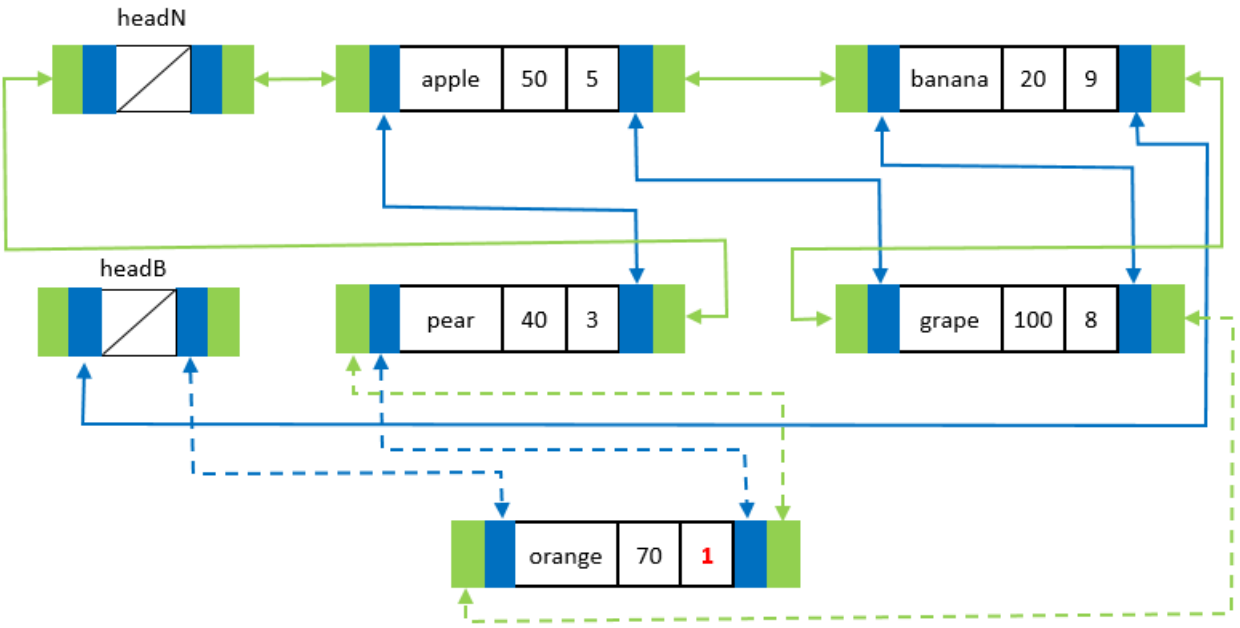


Fig. 7. DSL after the node insertion. Dashed blue arrows represent newly added links.

You are asked to implement two private methods below to carry out actual insertions of a node `node` into the N- and B-lists, respectively.

```
private void insertN(Node node, Node prev, Node next)
private void insertB(Node node, Node prev, Node next)
```

Each method inserts `node` between two nodes `prev` and `next` via updating either some `previousN` and `nextN` links or some `previousB` and `nextB` links.

3.2 Restocking

Regularly the store is restocked with fruits of multiple types. This is implemented by the following method:

```
public void restock(String fruitFile) throws FileNotFoundException,
                                              IllegalArgumentException
```

The parameter fruitFile is the name of a file which lists fruits line by line, where each line starts with the fruit name, follows with one or more blanks or `\t`, and ends with its quantity. Below is an example file.

```
pear      40
apple     50
grape     100
banana    20
```

Assumption e) on the inventory file also applies here, along with the following assumption:

g) Each line displays the name of a different fruit and its quantity.

If some fruit in the `fruitFile` is specified with a negative quantity, throw an `IllegalArgumentException`. If the quantity is zero, simply ignore the fruit.

The lines in the `fruitFile` are **not** sorted. For efficiency, you are asked to sort the fruits by name using the version of **quicksort** introduced in class. Within the `restock` method, declare two arrays `fruit[]` and `quant[]` to store the fruits and their quantities, and implements the following two private methods:

```
public void quickSort(String fruit[], Integer quant[], int size)
private int partition(String fruit[], Integer quant[], int first, int last)
```

The above methods will sort the fruits in the alphabetical order of name. After the sorting, every pair of entries in the arrays `fruit[]` and `quant[]` at the **same index** must store information about the **same fruit**.

Traverse the array `fruit[]`, the N-list, and the B-list simultaneously. Suppose that the fruit type `fruit[i]` is being scanned, where `i` is the index. Let N be the **first** encountered node such that N`.fruit.compareTo(fruit[i]) >= 0`. If no such node exists, N `== headN`. Two cases could arise:

1) N`.fruit.compareTo(fruit[i]) == 0`. Simply increase N`.quantity` by `quant[i]`.

2) Otherwise, `fruit[i]` is of a new type. Create a new node M to store `fruit[i]` and `quant[i]`. Add M to the N-list just before N by calling the method `insertN()`. Traverse the B-list to find the **first** available bin. It is found in one of the following three situations: a) when the currently visited node `cur` succeeds `headB` with `cur.bin` > 1; b) when `cur.bin` increases by more than 1 over that of `cur`'s predecessor; or c) when `cur.next == headB`. Store the number of the available bin in N`.bin`. Add M to the B-list by calling `insertB()`.

Suppose that there are n nodes in the DSL and k fruits on the restock list `fruitFile`. The running time of your implementation of `restock()` should be $O(n + k \log k)$.

4. Selling Fruits

Selling of fruits results in updates of their corresponding nodes. When fruits of one type are sold out, the node representing the fruit type must be deleted.

4.1 Removal

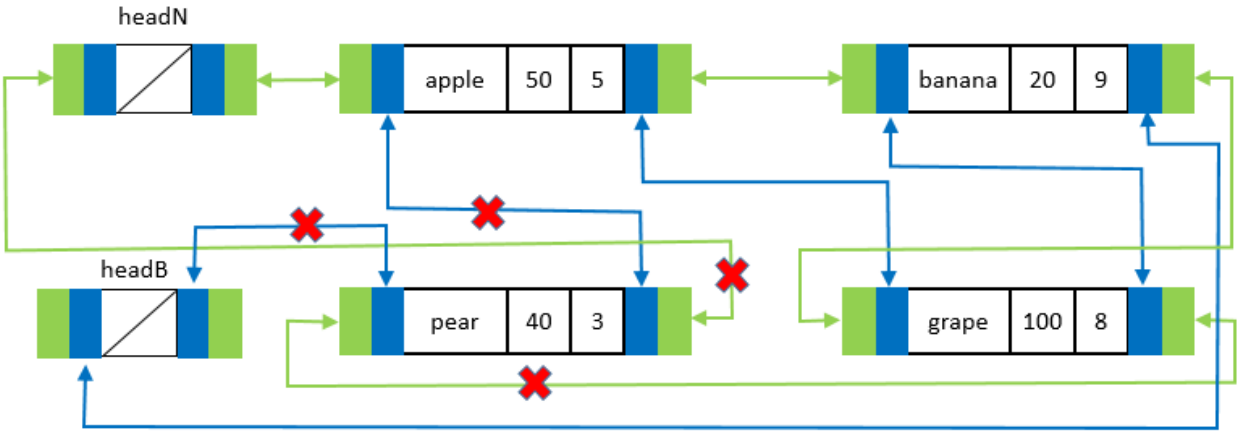
There are two removal methods, by fruit name and by bin number:

```
public void remove(String fruit)
public void remove(int bin) throws IllegalArgumentException
```

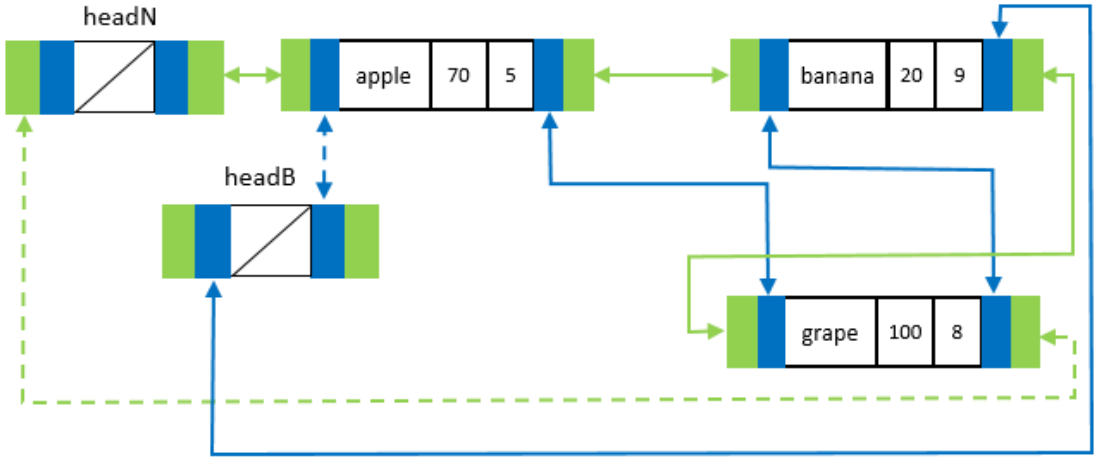
A removal starts by searching either in the N-list with the name `fruit` or in the B-list with the number `bin`. If no matching node is found, simply return. Otherwise, suppose the matching node is N. Call the following private method on N to remove it.

```
private void remove(Node node)
```

This method deletes the node from both the N-list and the B-list. An example of removal by fruit name is shown in Fig. 8. Another example, of removal by storage bin, is shown in Fig. 9.

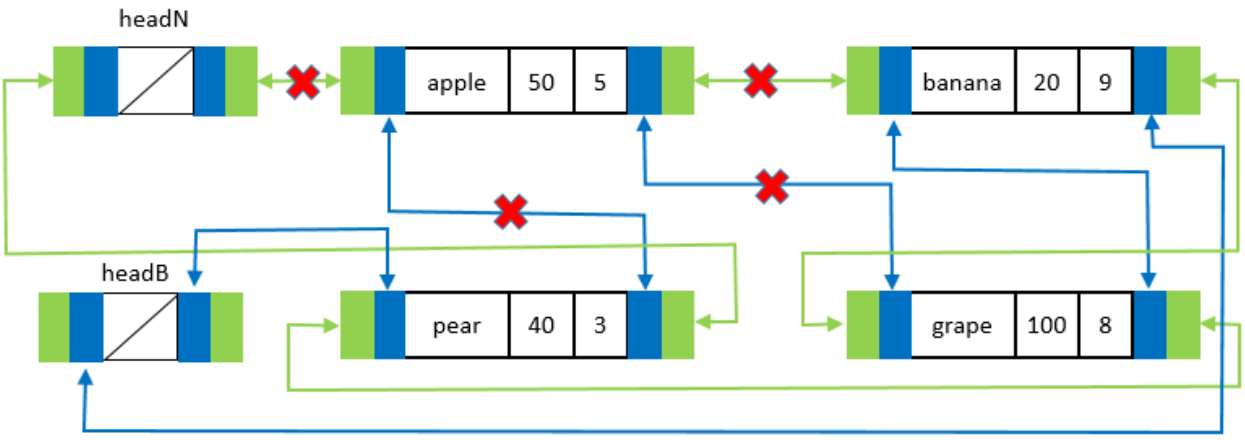


(a)

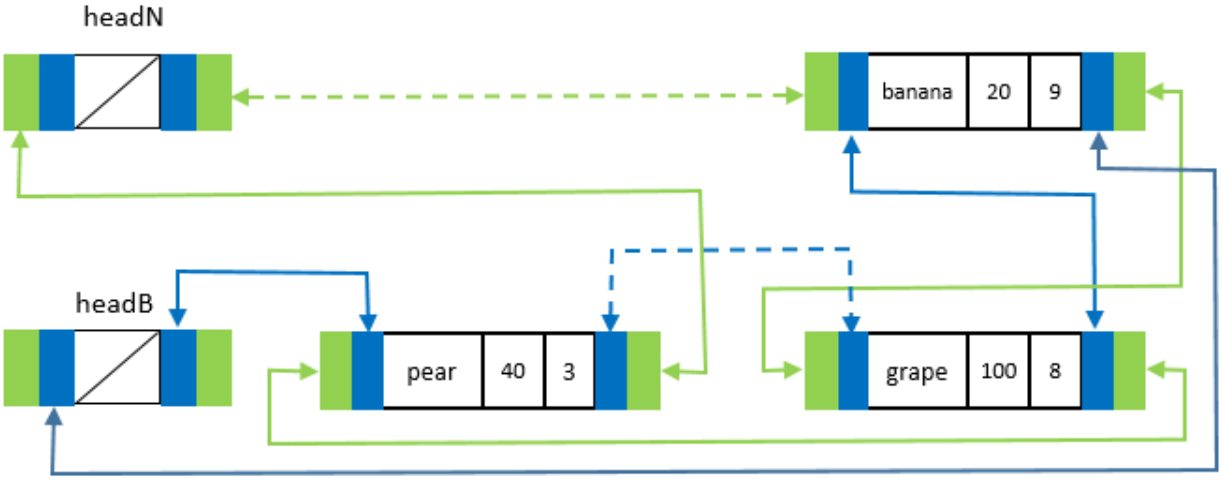


(b)

Fig. 8. Calling `remove("pear")`: (a) before and (b) after. Red crosses in (a) mark the links to be deleted, and dashed arrows in (b) mark the added ones.



(a)



(b)

Fig. 9. Calling `remove(5)`.

4.2 Sale

The shop does single sale and bulk sale, which are implemented by the two methods below:

```
public void sell(String fruit, int n) throws IllegalArgumentException
public void bulkSell(String fruitFile) throws FileNotFoundException,
                                               IllegalArgumentException
```

The method `sell()` first searches the N-list to see if the fruit is on stock. Nothing needs to be done if the answer is no. Otherwise, a node N is located for the fruit. The following is performed:

1) `n >=` N`.quantity`. Call the internal method `remove(`N`)` to delete the node.
2) `n <` N`.quantity`. Decrease N`.quantity` by `n`.

Fig. 10 shows the DSL after calling sell("banana", 5) on the list in Fig. 4.

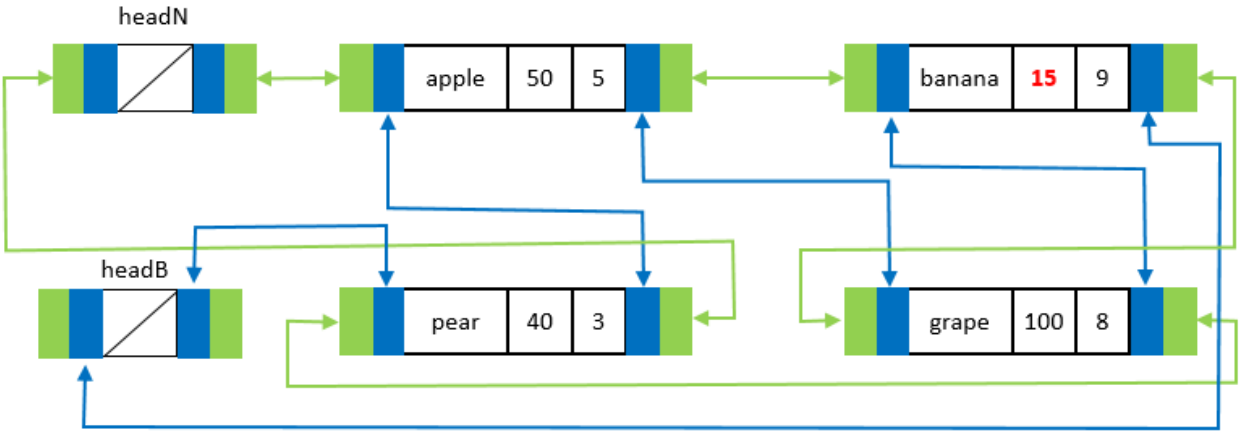


Fig. 10. DSL in Fig. 4 updated after sale of five bananas. The red number in the "banana" node shows the quantity after the sale.

While no check is needed for the correctness of the parameter `fruit`, an exception needs to be thrown if the parameter `n` is less than zero.

The method `bulkSell()` accepts a file with fruit names and quantities in exactly the same format accepted by the method `restock()` (see Section 3.2). Assumptions e) from Section 2 and g) from Section 3.2 both hold, so there is no need for file format checking. This method `bulkSell()` processes an order of multiple types of fruits in specified quantities. It executes the following steps:

1) Sort the purchased fruits and their quantities by name using the private method `quickSort()`, in a similar way as described for sorting in implementing `restock()`.

2) Simultaneously traverse the N-list and the sorted list of the fruits to be purchased. If the next fruit on the list is not on stock, just ignore its order. Otherwise, a node N with the next purchased fruit will be encountered. Let m be the ordered quantity of this fruit. Do the following.

    a. If m < 0 throw an IllegalArgumentException.
    b. If m == 0, ignore.
    c. If 0 < m < N`.quantity`, decrease N`.quantity` by m.
    d. If m `>=` N`.quantity`, call `remove(`N`)` to delete the node.

Suppose that there are n nodes in the DSL and k fruits on the purchase list `fruitFile`. The running time of your implementation of `bulkSell()` should be $O(n + k \log k)$.

Still consider the DSL in Fig. 4. Suppose the `fruitFile` has the following contents:

```
grape   200
pear    20
apple   10
jackfruit 5
```

After the sorting in Step 1, the arrays inside `bulkSell()`, say, `fruit[]` and `quantity[]`, to store the names and quantities of the ordered fruits, will respectively have the contents

```
{“apple”, “grape”, “jackfruit”, “pear”}
{10, 200, 5, 20}
```

Step 2 is then carried out via simultaneous traversals of the N-list and the array `fruit[]`. The fruit “`jackfruit`” is not on the list. The node “grape” gets deleted, as shown in Fig. 11.

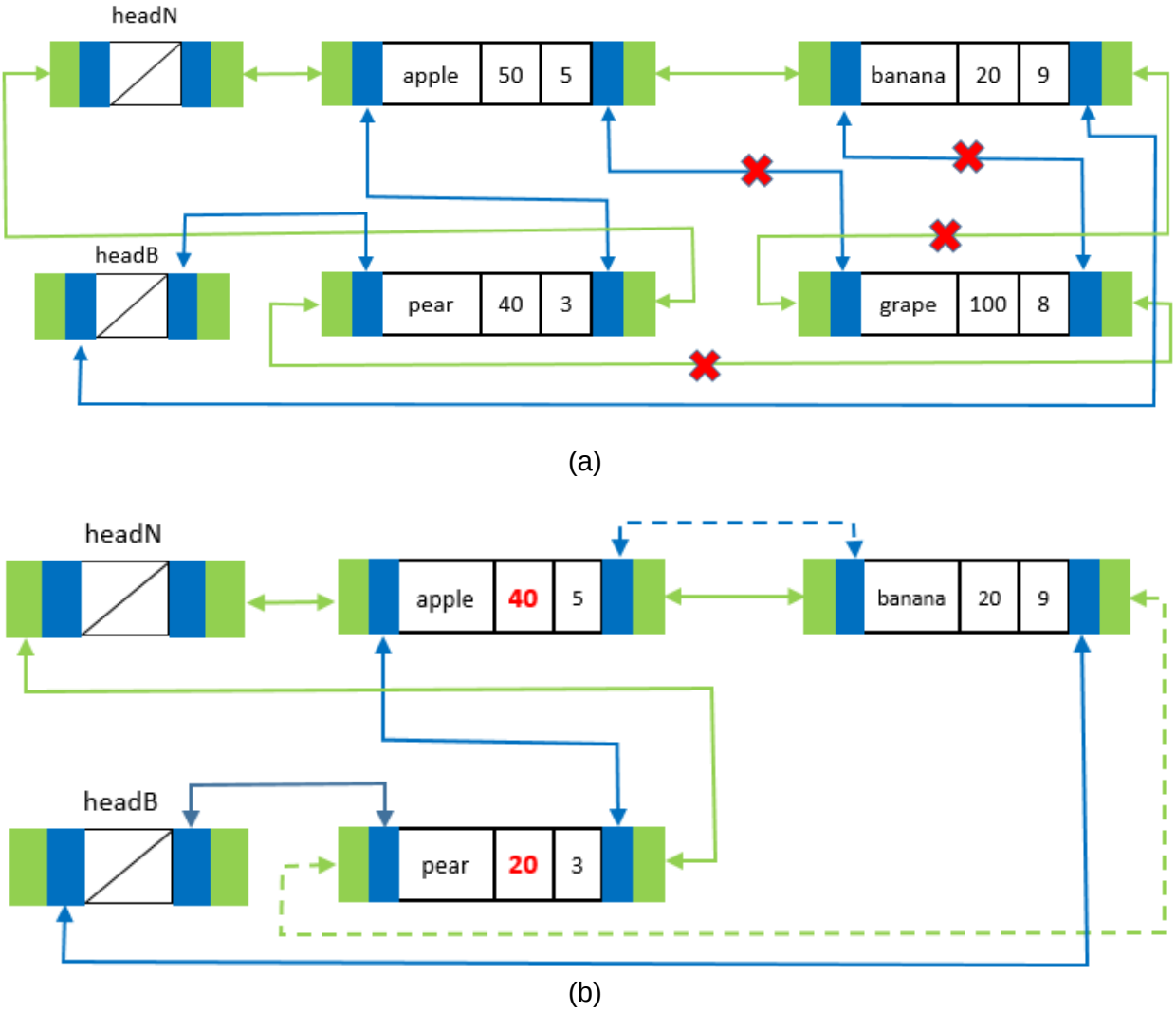


Fig. 11. The DSL from Fig. 4 (a) before and (b) after calling `bulkSell()` with the shown `fruitFile`. Entries colored red in (b) have been modified.

5. Inquiry and Storage Management

Queries for fruit availability can be performed. Every once in a while, the fruit store checks its inventory. Periodically, it compacts the space by re-arranging the bins with fruits next to each

other. Occasionally, it needs to clear all the fruits on stock (due to deterioration of unsold fruits, for instance).

5.1 Inquiry and Output Methods

This category has three methods:

```
public int inquire(String fruit)
public String printInventoryN()
public String printInventoryB()
```

The first method checks the quantity of a fruit on stock. The second method outputs a string that is printed out to be an inventory listing fruits in the alphabetical order. Here is sample output of the method from the DSL in Fig. 4.

```
fruit           quantity        bin
-----------------------------------
apple           50              5
banana          20              9
grape           100             8
pear            40              3
```

The following formatting rules apply to the output.

1) Entries within each column must be left-aligned.

2) The first characters in two adjacent columns are 16 character spaces apart.

You may use the length of a fruit name (which is at most 11 according to the fruit list in Appendix A). You can make the following assumption:

h) The values in the `quantity` and `bin` fields will not exceed 3 digits.

The method `printInventoryB()` outputs a string that is printed out to be an inventory sorted by the bin number.

```
bin             fruit           quantity
---------------------------------------
3               pear            40
5               apple           50
8               grape           100
9               banana          20
```

The two output formatting rules for `printInventoryN()` apply to `printInventoryB()`.

You also need to override the method `toString()`, which converts a DSL object into a string that would print out in exactly the same format required for `printInvertoryN()`.

5.2 Storage Methods

There are two methods to deal with storage bins:

```
public void compactStorage()
public void clearStorage()
```

The first method rearranges the bins containing fruits to be consecutive, starting at 1, while maintaining their original storage order. To implement this method, you need only traverse the B-list. See Fig. 12 for an example.

The method `clearStorge()` clears up the N-list and the B-list by setting the predecessors and successors of `headN` and `headB` to themselves.

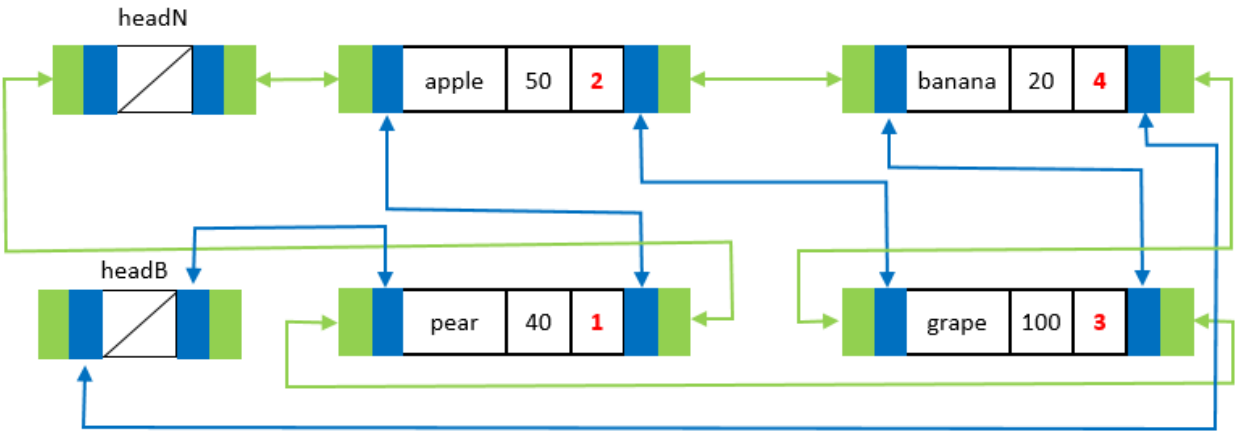


Fig. 12. The DSL in Fig. 4 after storage compacting. Fruits are now stored in bins 1, 2, 3, 4.

6. List Splitting

With an extra display room acquired, the store wants to split the original DSL of size n into two: DSL1 and DSL2 such that DSL1 stores the first $\lfloor n/2 \rfloor$ (i.e., `n/2` in Java) fruits, while DSL2 stores the last $\lceil n/2 \rceil$ (i.e., `n - n/2` in Java) fruits. Here, we suppose that the fruits are ranked 0, 1, …, $n-1$ by name. This operation is performed by the method

```
public Pair<DoublySortedList> split()
```

which returns an object `p` of the provided `Pair` class such that `p.first` references DSL1 and `p.second` references DSL2.

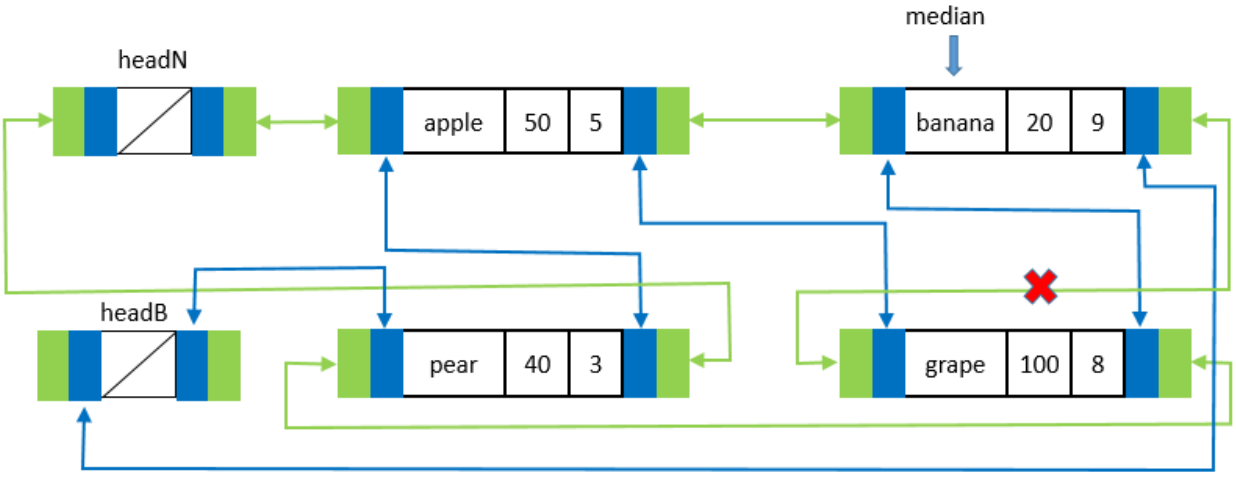
The algorithm for splitting carries out the following steps.

1) Split the N-list into DSL1 and DSL2 at the median node `M` by fruit name. The node is found via traversal of the N-list. The two resulting lists are sorted by fruit name but not by storage. Each needs to have a separate B-list reconstructed as a doubly-linked list.

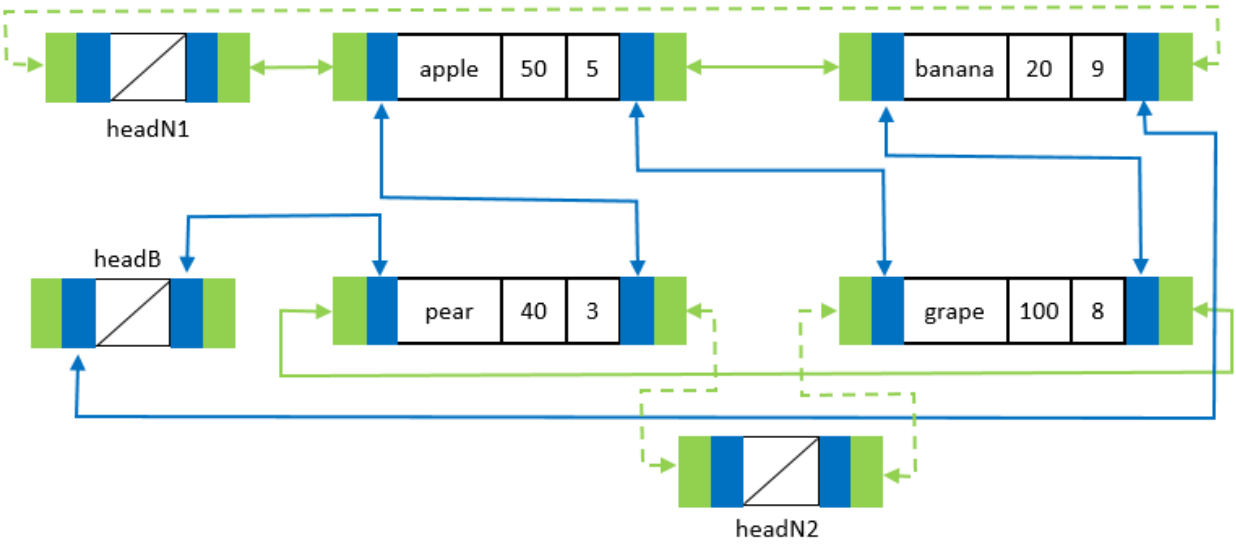
2) Traverse the B-list. For every node N encountered, do the following:

   a. If N`.fruit.compareTo(`M`.fruit) <= 0`, add the node N to the B-list of DST1.
   b. If N`.fruit.compareTo(`M`.fruit) > 0`, add the node N to the B-list of DST2.

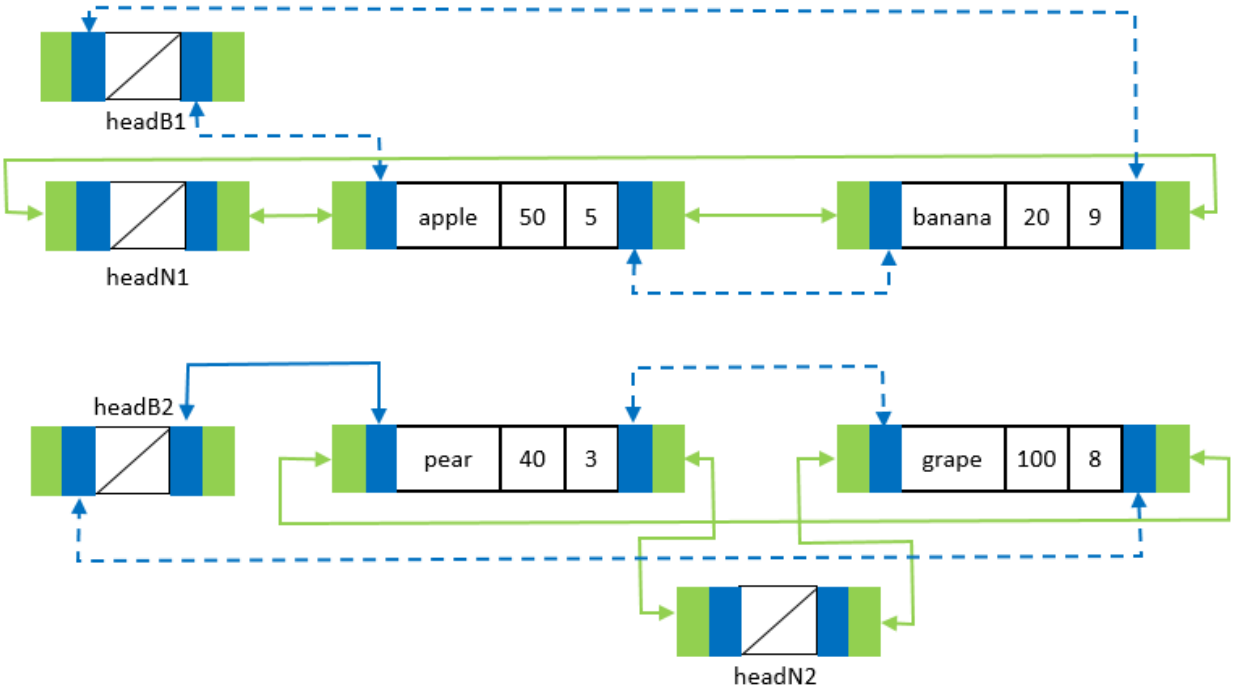
Fig. 14(a)-(c) illustrate the execution of the algorithm on the DSL in Fig. 4.



(a) Before split.



(b) After step 1 of split.



(c) After step 2 of split.

Fig. 13. Splitting a DSL into two. (a) Find the median node "banana" in the alphabetical order. (b) Split the original N-list into two. (c) Build two B-lists from the original B-list, using the median fruit name for partitioning.

The two resulting DSLs **must reuse** the nodes from the original DSL. You **cannot** make a copy of each node from the original list, and arrange these copy nodes into two lists respectively identical to those that would be generated from splitting.

7. Submission

Write your classes in the `edu.iastate.cs228.hw3` package. **Turn in the zip file not your class files.** Please follow the guideline posted under Documents & Links on Blackboard Learn.

You are not required to submit any JUnit test cases. Nevertheless, you are encouraged to write JUnit tests for your code. Since these tests will not be submitted, feel free to share them with other students.

Include the Javadoc tag `@author` in every class source file you have made changes to. Your zip file should be named `Firstname_Lastname_HW3.zip`.

A. Fruit Names

Below is a list of 36 common fruits relevant to the project:

- apple
- apricot
- avocado
- banana
- blackberry
- blueberry
- cantaloupe
- cherry
- coconut
- cranberry
- date
- durian
- fig
- grapefruit
- grape
- jackfruit
- kiwi
- kumquat
- lemon
- lime
- lychee
- mango
- mangosteen
- nectarine
- orange
- papaya
- peach
- pear
- pineapple
- plum
- pomelo
- prune
- raspberry
- strawberry
- tangerine
- watermelon