Lecture 5: Implementing Lists, Version 1

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Objectives

By the end of this lecture, you will know:

- How to implement lists using classes

By the end of this lecture, you will be able to:

- Use classes to implement recursively-defined data structures

1 Implementing Lists

Now that we have covered the basics of OO, let’s start applying OO to implement familiar data structures. Today, we start by implementing lists. We’ll implement lists of numbers for now, for simplicity.

In CS17, you saw a definition of lists along the lines of the following:

A list-of-numbers is either
* empty, or
* (cons number list-of-numbers)

Using this as a guide, we want to implement lists in Java.
Give it a try – can you turn this definition into a collection of classes, interfaces, abstract classes, etc. Note: if you have had some Java before, use only features and constructs that we have covered in the course so far.

Note the similarity between this and our previous setup of Boas and Dillos as Animals: there, we needed an interface for the shared type name, and a class for each variant. Following that, here's what you should have in Java (perhaps with different class/interface/variable names):

```java
public interface IList {}

public class EmptyList implements IList {
    public EmptyList() {}
}

public class NodeList implements IList {
    int first;
    IList rest;

    public NodeList(int fst, IList rst) {
        this.first = fst;
        this.rest = rst;
    }
}
```

**Side note for those with prior Java:** Likely, many of you wanted to use null in your solution. Hold that thought. It actually isn’t good OO practice, even though it is common practice in Java. We’ll discuss the null-based solution explicitly next week (and explain what’s wrong with it from an OO perspective).

How could we create a list of three numbers with these classes?

```java
new NodeList(3, new NodeList(6, new NodeList(1, new EmptyList())))
```

With a class hierarchy and a sample of data in hand, we can turn to writing methods on our list class.

## 2 Methods

Here’s the IList interface that we want to implement in this lecture. (Note: I’m intentionally not using javadoc to make the notes more compact – the posted code uses Javadoc instead, as you should when writing programs for homework, etc)

```java
public interface IList {
    public boolean isEmpty(); // is the list empty?
    public IList addFirst(int elt); // add element to front of the list
    public IList remEltOnce(int elt); // remove first occurrence of elt
    public int head(); // get the head of the list
    public IList tail(); // get the tail of the list
    public int size(); // the number of elements in the list
}
```
We’ll work on these in order.

### 2.1 isEmpty

This one is straightforward: each list class returns a boolean constant indicating whether or not it is empty. For example:

```java
public class EmptyList implements IList {
    public boolean isEmpty() {
        return true;
    }
}
```

### 2.2 addFirst

Here, we create a new NodeList with the given element as the first item and this as the rest of the list.

```java
public class EmptyList implements IList {
    public IList addFirst(int elt) {
        return new NodeList(elt, this);
    }
}
```

Note that this code is identical between the two list classes, so arguably you would make an abstract class to share this code. We skipped this in lecture so we could get through the other methods, but it is shown in the posted code.

Now that we have `addFirst`, we can rewrite our example list as follows:

```java
new EmptyList().addFirst(1).addFirst(6).addFirst(3)
```

Note that the elements appear to be written in the opposite order from our original example. You should convince yourself that these two expressions will produce lists with the same elements in the same order.

### 2.3 remEltOnce

In the `EmptyList` case, there’s nothing to remove, so the method just returns `this`. In the `NodeList` case, we check whether the node contains the element, then either remove it or pass the computation on to the rest of the list to perform:

```java
public class NodeList implements IList {
    public IList remEltOnce(int remelt) {
        if (remelt == this.first) {
```
Note that this is the same recursive solution that you would have written in CS17. We don’t lose recursion as a technique just because we have switched to Java.

2.4 head and tail

What if we want to get the head and tail (or first and rest) of the list? You might be tempted to do this by accessing the first and rest fields directly, as in the following example:

```java
public class ListTest {
    // is 2 the first element in the list?
    public boolean startsWithTwo(IList aList) {
        return (aList.first == 2);
    }
}
```

Stop and think: what do you expect will happen if you enter this code in Eclipse?

Eclipse flags this code, reporting that it can’t find the first field in aList (which has type IList). Should we change the parameter type to NodeList? That would make the error go away, but it is meaningful to ask whether an empty list starts with 2 (the answer would just be false).

Rather than access fields directly (which isn’t good programming practice anyway), we will introduce methods for getting the first and rest portions of the list. In NodeList, they look like:

```java
public class NodeList implements IList {
    public int head() {
        return this.first;
    }
    public IList tail() {
        return this.rest;
    }
}
```

What happens in EmptyList, however? There are no first or rest components to return, so what should happen? Both of these methods should raise errors, since it isn’t meaningful to break down an empty list:

```java
public class EmptyList implements IList {
    public int head() {
        throw new RuntimeException("Attempt to take head of empty list");
    }
}
```
In Java, `RuntimeExceptions` are for errors that you can’t really recover from gracefully (like division by 0). They result in the program stopping completely. Later in the course, we will see more sophisticated situations of handling errors.

Unlike the exception that you saw in lab, you don’t need `throws` annotations for `RuntimeExceptions`. They are the closest Java analog to the simple error raising that you did in CS17.

### 2.5 size

Finally, we turn to a method that returns the size of the list. You’ve written recursive length functions many times in CS17, and we could certainly do the same here (following a pattern similar to that we used for `remEltOnce`).

But can we do that computation more efficiently? The size of the list doesn’t change dynamically: it’s a fixed value for any particular list, so it seems worth just storing it in a field and returning the field value whenever someone calls the `size` method. Specifically, we’d like to do the following:

```java
public class NodeList implements IList {
    int first;
    IList rest;
    int eltCount;

    public int size() {
        return this.eltCount;
    }
}
```

The interesting question here lies in the constructor: how should the constructor set up the value of `eltCount`? As a reminder, here is the constructor before we add the `eltCount` field:

```java
public class NodeList implements IList {
    int first;
    IList rest;

    public NodeList(int fst, IList rst) {
        this.first = fst;
        this.rest = rst;
    }
}
```

Should we just add a parameter to the constructor that asks for the size? That would be inconvenient for the programmer who uses our list classes. For example, the list-example code we wrote before would now have to change to
new NodeList(3, new NodeList(6, new NodeList(1, new EmptyList(), 1), 2), 3)

(where the “1), 2), 3” at the end of the line adds the sizes). Our definition of the addFirst method would also be affected. The eltCount field is our own implementation detail to make the size method more efficient, so it should not be visible to the user of our code.

2.5.1 Adding Computation to Constructors

Constructors are just methods that are used to create objects. Like all methods, they can do arbitrary computation to complete their tasks. In this case, we want the constructor to compute the size when we create the list, then store that value in the field. Here’s the code:

```java
public class NodeList implements IList {
    int first;
    IList rest;
    int eltCount;

    public NodeList(int fst, IList rst) {
        this.first = fst;
        this.rest = rst;
        this.eltCount = 1 + rst.size();
    }
}
```

For the empty list, we simply initialize the eltCount to 0.

3 Creating an Abstract Class

With the addition of the eltCount, we now have another bit of code that is shared between the EmptyList and NodeList classes. This definitely points to an abstract class to share these details. Trying to write it for yourself is a terrific exercise:

```
Try creating this abstract class (write it on paper) before looking at the posted code for today’s lecture (which shows the solution)
```

If you look at the posted code, you’ll see that the implements IList annotation has also elevated to the abstract class. Since the interface is common to all classes that extend AbsList, it makes sense to annotate the abstract class instead.

4 Printing Lists: toString methods

One last tidbit, which is not about list classes in particular, but does show you a practical aspect of working in Java.

Sometimes, we just want to print out the result of a computation without going through a test case. For example, we might want to have the following code in the main method of our TestList class:
public class ListTest {

    public static void main(String[] args) {
        IList list1 = (new EmptyList()).addFirst(3).addFirst(6).addFirst(1);
        System.out.println(list1);
    }
}

If we do this, we see something like

lec05.NodeList@15db9742

What is this? Remember our memory maps? This is saying that there’s an object at memory address 15db9742 that was created from the NodeList class in the lec05 package.

Not very useful, right?

In Java, when you define classes, you also want to tell Java what to print out about objects in the class when needed. We do this by putting a method named toString in the EmptyList and NodeList classes.

```
public class EmptyList implements IList {
    @Override
    public String toString() {
        return "empty";
    }
}

public class NodeList implements IList {
    @Override
    public String toString() {
        return this.first + "", " + this.rest.toString();
    }
}
```

With these, our main method snippet now displays

1, 6, 3, empty

You don’t need to mention toString in the interface: every Java class gets a default toString method that you can override with a custom definition, as we did here.

The @Override annotation indicates that we are providing a refined definition of a method that otherwise already exists in the class. Nothing goes wrong if you leave it off, but it is good practice to include it.
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