

Welcome Back!!!!

1337 h4ckz0r5!

- DATA STRUCTURE (WAY TO MANAGE STORED INFORMATION)
 - Object (technically)
 - ARRAY
 - MATRIX (MULTI-DIMENSIONAL)
 - ArrayList
- } STATIC DATA STRUCTURES (FIXED IN SIZE)

Suppose the method `int sign(int x)` returns 1 if x is positive, -1 if x is negative and 0 if x is 0. Given

`int[] nums = {-2, -1, 0, 1, 2}`

what are the values of the elements of `nums` after the following code is executed?

```
int k;  
for (k = 0; k < nums.length; k++)  
{  
    nums[k] -= sign(nums[k]);  
    nums[k] += sign(nums[k]);  
}
```

- (A) -2, -1, 0, 1, 2 |
~~(B) -1, 0, 0, 0, 1~~ O
~~(C) 0, 0, 0, 0, 0~~ O
~~(D) -2, 0, 0, 2, 3~~ O
~~(E) 2, 0, 0, 0, 2~~ LOTS

STUDENT OUTLINE

Lesson 29 – Linked Lists

DYNAMIC
DATA
STRUCTURE

INTRODUCTION: In this lesson you begin to study a new data structure, the **linked list**, which is used to implement a **list of elements arranged in some kind of order**. The linked list structure uses memory that **shrinks and grows as needed** but not in the same way as arrays. The discussion of linked lists includes the specification and implementation of a **node class**, which incorporates the fundamental notion of a **single element of a linked list**.

The key topics for this lesson are:

- A. Declarations for a Linked List
- B. Methods for Manipulating Nodes
- C. Implementing Linked Lists
- D. Traversing a Linked List
- E. Pitfalls of Linked Data Structures

| | | |
|--------------------|----------|-------------|
| VOCABULARY: | NODE | LINKED LIST |
| | TRAVERSE | NODE |
| | NODE | |

DISCUSSION: A. Declarations for a Linked List

1. A linked list is a **sequence of elements arranged one after another**, with each element connected to the next **element by a “link.”** The link to the next element is combined with each element in a component **called a *node*.** A node is represented pictorially as a box with an element written inside of the box and a link drawn as an arrow and used to connect one node to another.

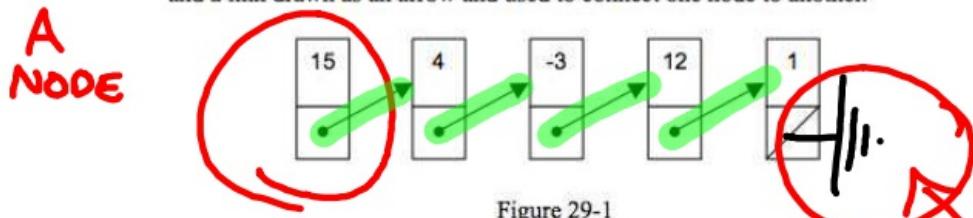


Figure 29-1

In addition to connecting two nodes, **the links also place the nodes in a particular order**. In Figure 29-1 above, the five nodes form a chain with the first node linked to the second; the second node linked to the third node; and so on until the last node is reached. The last node is a special case since it is not linked to another node and is indicated with a diagonal line.

ACTS
LIKE A
STOP SIGN

A SELF-REFERRING OBJECT

DATA TO STORE

2. Each node contains two pieces of information: an element and a reference to another node. This can be implemented as a Java class for a node using an instance variable to hold the element, and a second instance variable that is a reference to another node as follows:

```
public class ListNode
{
    private Object value; // the element stored in this node
    private ListNode next; // reference to next node in List
    ...
}
```

3. The declaration seems circular and in some ways it is, but the compiler will allow such definitions. A ListNode will have two data members, an Object and a reference to another ListNode. The instance variable next will point to the next ListNode in a linked list.
4. The ListNode class is constructed so that the elements of a list are objects (i.e., have the Object data type). Since any class extends Object, you can put any kind of object into a list, including arrays and strings.

5. Whenever a program builds and manipulates a linked list, the nodes are accessed through one or more references to nodes. Typically, a program includes a reference to the first node (first) and a reference to the last node (last).

```
ListNode first;
ListNode last;
```

A program can proceed to create a linked list as shown below. The first and last reference variables provide access to the first and last nodes of the list

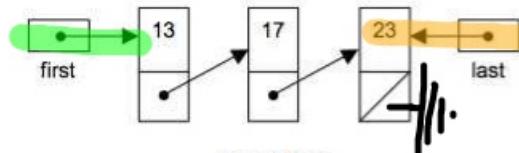


Figure 29-2

6. Figure 29-2 illustrates a linked list with a reference to the first node that terminates at the final node (indicated by a diagonal line in the reference field of the last node). Instead of a reference to another node, the final node contains a null reference, which is a special Java constant. The null reference can be used for any reference variable that has nothing to refer to. There are several common situations where the null reference is used:

- a. When a reference variable is first declared and there is not yet an object for it to refer to, it can be given an initial value of the null reference.
- b. The null reference occurs in the link part of the final node of a linked list.
- c. When a linked list does not yet have any nodes, the null reference is used for the first and last reference variables to indicate an empty list.

In a program, the null reference is written as the keyword null.

B. Methods for Manipulating Nodes

See, *ListNode.java*

1. Methods for the `ListNode` class will consist of those for creating, accessing, and modifying nodes
2. The constructor for the `ListNode` class is responsible for creating a node and initializing the two instance variables of a new node. The node's constructor has two arguments, which are the initial values for the node's data and link variables. The constructor's implementation copies its two parameters to the instance variables, `value` and `next`:

```
public ListNode(Object initialValue, ListNode initNext)  
// post: constructs a new element with object initialValue,  
// followed by next element  
{  
    value = initialValue;  
    next = initNext;  
}
```

3. As an example, the constructor can be used by a program to create the first node of a linked list.

```
ListNode first;  
first = new ListNode(new Integer(23), null);
```

After execution of the two statements, `first` refers to the header node of a small linked list that contains just one node with the `Integer` 23.



YIELDS THIS PICTURE

EXTERNAL (MANAGE)

Since primitive data types (`int`, `double`, `boolean`, etc.), are not objects, it is necessary to convert them to objects using the appropriate wrapper class (`Integer` for `int`, `Double` for `double`, etc.) to construct a list.

Accessors

Modifiers

4. Getting and setting the data and link of the node is accomplished with an accessor method and a modification method for each of its instance variables as follows:

```
public Object getValue()  
// post: returns value associated with this element  
{  
    return value;  
}  
  
public ListNode getNext()  
// post: returns reference to next value in list  
{  
    return next;  
}  
  
public void setValue(Object theNewValue)  
{  
    value = theNewValue;  
}  
  
public void setNext(ListNode theNewNext)  
// post: sets reference to new next value  
{  
    next = theNewNext;  
}
```

} NOT TYPICALLY USED

5. The following short program using ListNode will illustrate the syntax of accessing the data members of a ListNode.

```
public static void main(String[] args)  
{  
    ListNode list; ← EXTERNAL  
  
    list = new ListNode(new Integer(13), null);  
  
    System.out.println("The node contains: " +  
        (Integer)list.getValue());  
  
    list.setValue(new Integer(17));  
    System.out.println("The node contains: " +  
        (Integer)list.getValue());  
}
```

Run Output:

The node contains: 13
The node contains: 17

TYPECAST
(LIKE AN
OLD SCHOOL
ArrayList)

C. Implementing Linked Lists

See *ListDemo.java* and *SinglyLinkedList.java*

MANAGES THE LIST.

1. In this section, we will look at the implementation of a linked list of *ListNode* objects. This class encapsulates the list operations that maintain the links as the list is modified. To keep the class simple, we will implement only a singly linked list, and the list class will supply direct access only to the first list element.

2. The *SinglyLinkedList* class holds a reference *first* to the first *ListNode* (or *null*, if the list is completely empty). Access to the first node is provided by the *getFirst* method. If the list is empty, a *NoSuchElementException* is thrown (see Lesson 28 *Exceptions*).

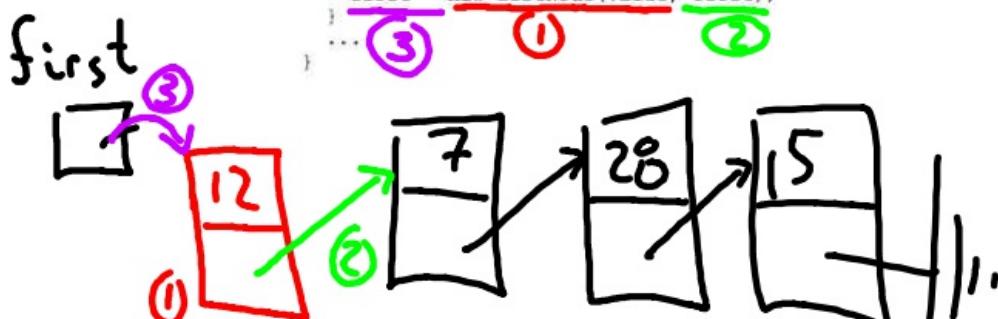
```
class SinglyLinkedList
{
    private ListNode first; ← EXTERNAL
    public SinglyLinkedList()
    {
        first = null;
    }

    public Object getFirst()
    {
        if (first == null)
        {
            throw new NoSuchElementException();
        }
        else
            return first.getValue();
    }
}
```

} ERROR TRAP

3. Additional nodes are added to the head of the list with the *addFirst* method. When a new link is added to the list, it becomes the head of the list, and the link that the old list had becomes the next link:

```
class SinglyLinkedList
{
    ...
    public void addFirst(Object value)
    {
        first = new ListNode(value, first);
    }
    ...
}
```

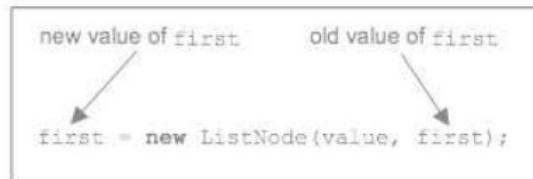


4. The statement `ListNode(value, first)` invokes the constructor. The line of code

```
first = new ListNode(value, first);
```

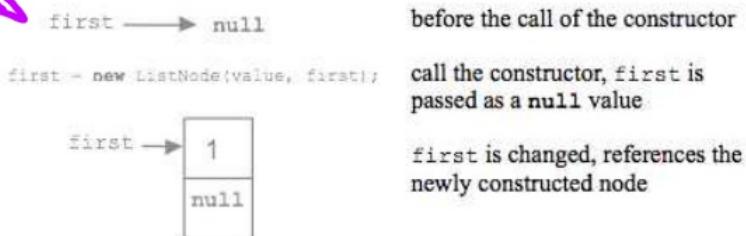
is broken down as follows:

-  a. The `new` command allocates enough memory to store a `ListNode`.
 b. The new `ListNode` will be assigned the values of `value` and `first`.
 c. The address of this newly constructed `ListNode` is assigned to `first`.
 d. It is important to understand the old and new values of `first`:

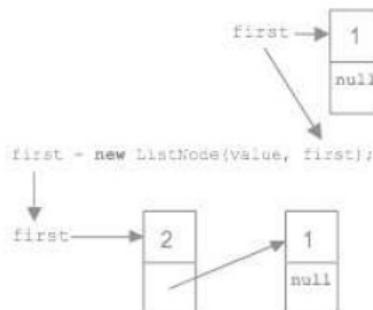


5. When `value = 1, first = null`. A new node is constructed with the values 1 and `null`. `first` points to this new node. In a sense, the constructor provides a new node between the variable `first` and the node that `first` formerly referenced.

EMPTY
LIST



6. When `value = 2, first` is already pointing to the first node of the linked list. When the constructor is called, the new node is constructed and placed between `first` and the node `first` used to point to.



The value of `first` passed to the `ListNode` constructor is used to initialize the next field of the new node.

D. Traversing a Linked List - Method `printList`

1. To traverse a list means to start at one end and visit all the nodes, solving a problem along the way. In the case of method `printList`, the task is to print the value field from each node.

*TEMPORARY
EXTERNAL
LIKE X++
IN AN ARRAY
TRAVERSAL*

```
class SinglyLinkedList
{
    ...
    public void printList()
    {
        ListNode temp = first; // start from the first node
        while (temp != null)
        {
            System.out.print(temp.getValue() + " ");
            temp = temp.getNext(); // go to next node
        }
        ...
    }
}
```

*AS LONG AS WE'VE NOT REACHED THE STOP SIGN
DISPLAY ADVANCE*

- a. Because `temp` is an alias to `first`, we can use it to traverse the list without altering the reference to the start of the list. The `ListNode` variable, `temp`, will contain `null` when we are done.
- b. Until `temp` equals `null`, the `while` loop will do two steps at each node; print the data field, then advance the `temp` reference.
- c. The statement, `temp = temp.getNext()`, is a very important one as this is how we move to the next node.

2. Another common list traversal problem is counting the number of nodes in the list. The lab exercise will ask you to solve this problem.

How to
LOSE
YOUR HAIR

E. Pitfalls of Linked Data Structures

1. A linked list must end with a `null` value. Without such a marker at the end of the list, a routine cannot “see” the end of the data structure. This assignment of a `null` value at the end of the list is often taken care of when a new node is packaged or through the use of a constructor.
2. When a reference variable is `null`, it is a programming error to invoke one of its methods or to try to access one of its instance variables. For example, a program may maintain a reference to the first node of a linked list, as follows:

```
ListNode first;
```

Initially, the list is empty and `first` is the null reference. At this point, it is a programming error to invoke one of the `ListNode`'s methods. The error would occur as a `NullPointerException`.

SUMMARY/ REVIEW:

You have just been taught your first dynamic data structure, a linked list. The concept of indirection makes dealing with references a bit more difficult, but careful reading and lots of diagrams will help. Following a working program is a good start; but only by writing code will you develop proficiency with lists. The lab exercises for the next few lessons will enhance your understanding of linked lists.

ASSIGNMENT: Lab Exercise L.A.29.1, *List1*