Chapter 10

Dynamic Data Structures

- Vectors
- Linked Data Structures

Overview

- This chapter is about data structures that are *dynamic*:
  They can grow and shrink while your program is running
- Vectors are similar to arrays but are more flexible.
- Linked lists are a dynamic data structure commonly used in many programming languages.

Vectors

"Well, I'll eat it," said Alice, "and if it makes me grow larger, I can reach the key; and if it makes me grow smaller, I can creep under the door; so either way I'll get into the garden…"

Lewis Carroll, *Alice's Adventures in Wonderland*

VECTORS

Think of them as arrays that can get larger or smaller when a program is running.

Using Vectors

- Vectors are not automatically part of Java
  - » they are in the `util` library
  - » you must import `java.util.*`

- Create a vector with an initial capacity of 20 elements:
  ```
  Vector v = new Vector(20);
  ```

Initial Capacity and Efficiency: a Classic Engineering Tradeoff

- *Engineering* involves making difficult tradeoffs
  - » *"There's no such thing as a free lunch."*
    - – an American saying
  - » Usually, if you gain something you lose something somewhere else
- Choosing the initial capacity of a vector is an example of a tradeoff
  - » making it too large wastes allocated memory space
  - » making it too small slows execution
    - – it takes time to resize vectors dynamically
- Solution?
  - » optimize one at the expense of the other
  - » or make good compromises
    - – choose a size that is not too big and not too small

Vector Syntax

- The idea is the same as for arrays, but the syntax is different
- As with arrays, the index must be in the range 0 to (size-of-the-vector – 1)

Array: `a` is a `String` array

```
a[i] = "Hi, Mom!";

String temp = a[i];
```

Vector: `v` is a vector

```
v.setElementAt("Hi, Mom!", i);

String temp =
   (String)v.elementAt(i);
```

Instead of the index in brackets and = for assignment, use vector method `setElementAt` with two arguments, the value and the index

Use vector method `elementAt(int index)` to retrieve the value of an element

Note: the cast to `String` is required because the base type of vector elements is `Object`

Vector Methods

- The vector class includes many useful methods:
  - » constructors
  - » array-like methods, e.g. `setElementAt` & `elementAt`
  - » methods to add elements
  - » methods to remove elements
  - » search methods
  - » methods to work with the vector's size and capacity, e.g. to find its size and check if it is empty
  - » a `clone` method to copy a vector

- See the text for more information

A little Detail about **`setElementAt`**

"The devil's in the details."

– an American engineering saying

- Vectors put values in successive indexes
  - » `addElement` is used to put initial values in a vector
  - » new values can be added only at the next higher index

- You cannot use `setElementAt` to put a value at just any index
  - » `setElementAt` can be used to assign the value of an indexed variable only if it has been previously assigned a value with `addElement`

Base Type of Vectors

- The base type of an array is specified when the array is declared
  - » all elements of arrays must be of the same type

- The base type of a vector is `Object`
  - » elements of a vector can be of any class type
  - » in fact, *elements of a vector can be of different class types!*
  - » to store primitive types in a vector they must be converted to a corresponding wrapper class

Good Programming Practice

Although vectors allow elements in the same vector to be of different class types, it is best not to have a mix of classes in the same vector -

– it is best to have all elements in a vector be the same class type.

Detail: One Consequence of the Base Type of Vectors Being `Object`

- The following code looks very reasonable but will produce an error saying that the class `Object` does not have a method named `length`:

```
Vector v = new Vector(10);
String greeting = "Hi, Mom!";
v.addElement(greeting);
System.out.println("Length is " +
   (v.elementAt(0)).length());
```

- `String`, of course, does have a `length` method, but Java sees the type of `v.elementAt(0)` as `Object`, not `String`
- Solution? Cast `v.elementAt(0)` to `String`:

```
System.out.println
   ("Length is " +((String)(v.elementAt(0))).length());
```

Arrays Versus Vectors

Arrays

Bad:

- Size is fixed when declared
- Inefficient storage: can use a partially full array, but space has been allocated for the full size
- If one more value needs to be added past the maximum size, the array needs to be redeclared

Good:

- More efficient (faster) execution
- Allows primitive type elements

Vectors

Good :

- Size is not fixed
- Better storage efficiency: a partially full vector may be allocated just the space it needs
- If one more value needs to be added past the maximum size, the vector size increases automatically

Bad:

- Less efficient (slower) execution
- Elements must be class types (primitive types not allowed)

One More Detail: Size Versus Capacity

- Be sure to understand the difference between *capacity* and *size* of a vector:
  - » *capacity* is the declared size of the vector (*v.capacity()*)
    - – the current maximum number of elements
  - » *size* is the actual number of elements being used (*v.size()*)
    - – the number of elements that contain valid values, not garbage
    - – remember that vectors add values only in successive indexes

- Loops that read vector elements should be limited by the value of `size`, not `capacity`, to avoid reading garbage values

Programming Tip: Adding to a Vector

- Can use `addElement`
  - » adds elements at index positions in order
- Can also use `insertElementAt` to add to a vector
  - » specify the position where you want to insert the element:

```
v.insertElementAt(element, index);
```

  - » `index` must be less than or equal to `size`
  - » If `index` is equal to `size`, then `element` will be inserted at the end (the same place where addElement would add it).
  - » If `index` is greater than `size`, you will get a run-time error that says `ArrayIndexOutOfBoundsException`
  - » All elements at position `index` or higher will have their index increased by 1
  - » There is also a **`removeElementAt(index)`** method

Programming Tip: Increasing Storage Efficiency of Vectors

- A vector automatically increases its capacity if elements beyond its current capacity are added (see next slide)
- But a vector does not automatically decrease its capacity if elements are deleted
- The method `trimToSize()` shrinks the capacity of a vector to its current size so there is no extra, wasted space
  - » the allocated space is reduced to whatever is currently being used
- To use storage more efficiently, use `trimToSize()` when a vector will not need its extra capacity later

Declaring a Vector

```
Vector v = new Vector (10); // capacity=10,
   doubles

Vector v = new Vector (); // capacity=10, doubles

Vector v = new Vector (n); // capacity=n, doubles

Vector v = new Vector (n,p); // capacity=n,
   increases by p
```

And Another Detail: Correcting the Return Type of `clone`

- The method `clone` is used to make a copy of a vector but its return type is `Object`, not `Vector`
  - » of course you want it to be `Vector`, not `Object`

- So, what do you do?
  - » Cast it to `Vector`

```
Vector v = new Vector(10);
Vector otherV;
otherV = v;
Vector otherV = (Vector)v.clone();
```

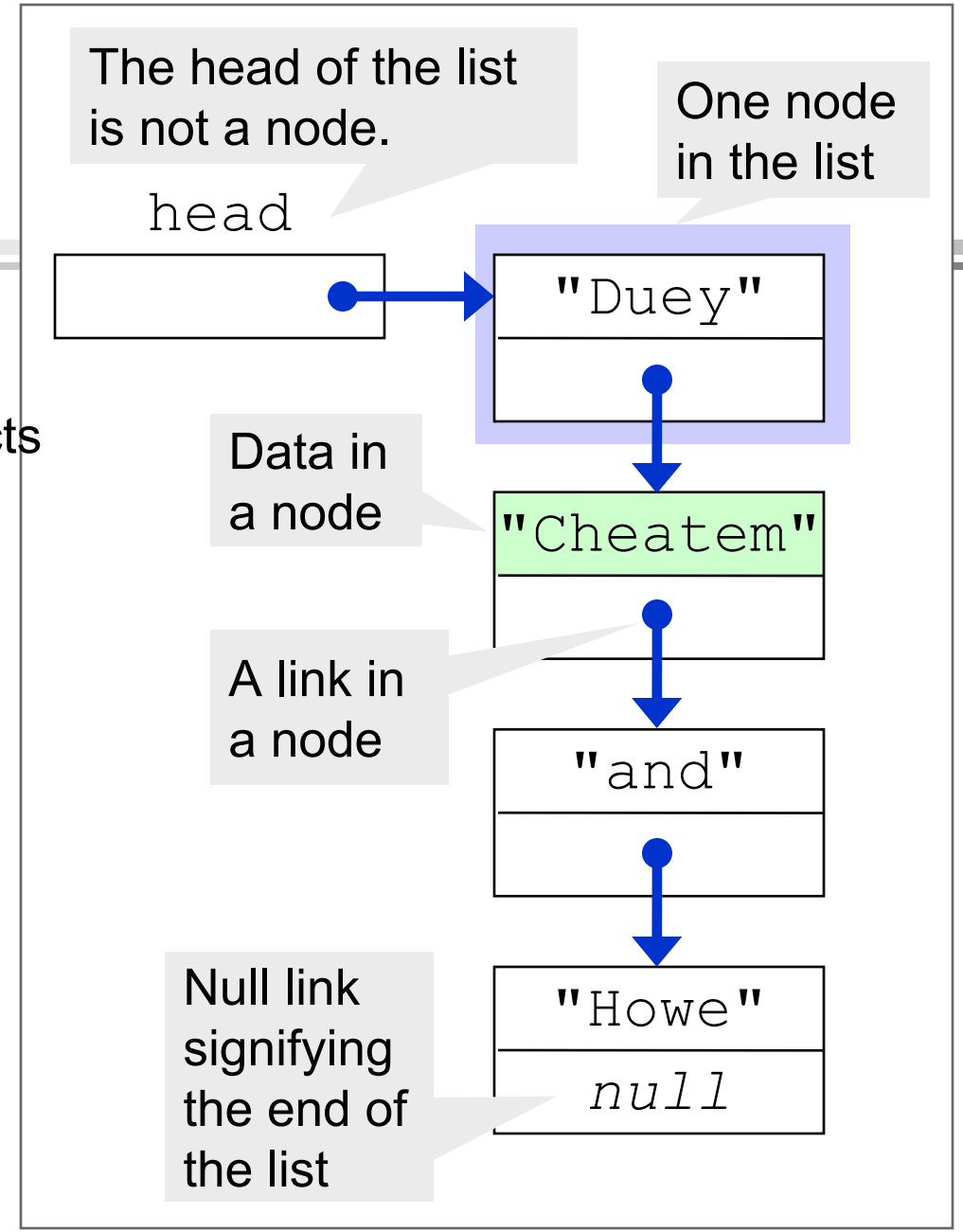
This just makes `otherV` another *name* for the vector `v` (there is only one copy of the vector and it now has two names)

This creates a ***second*** copy of `v` with a different name, `otherV`

Linked Lists

- *Linked list* consists of objects known as nodes
- Each node has a place for data and a link to another node
- Links are shown as arrows

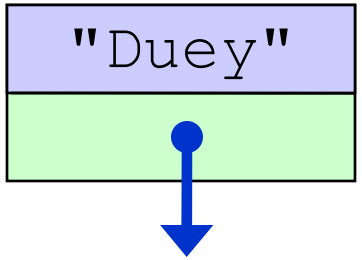
- Each node is an object of a class that has two instance variables: one for the data and one for the link



ListNode Class: Instance Variables and Constructor

```
public class ListNode
{
    private String data;
    private ListNode link;

    public ListNode(String newData, ListNode linkValue)
    {
        data = newData;
        link = linkValue;
    }
```



Two parameters for the constructor:

- data value for the new node
- Link value for the new node

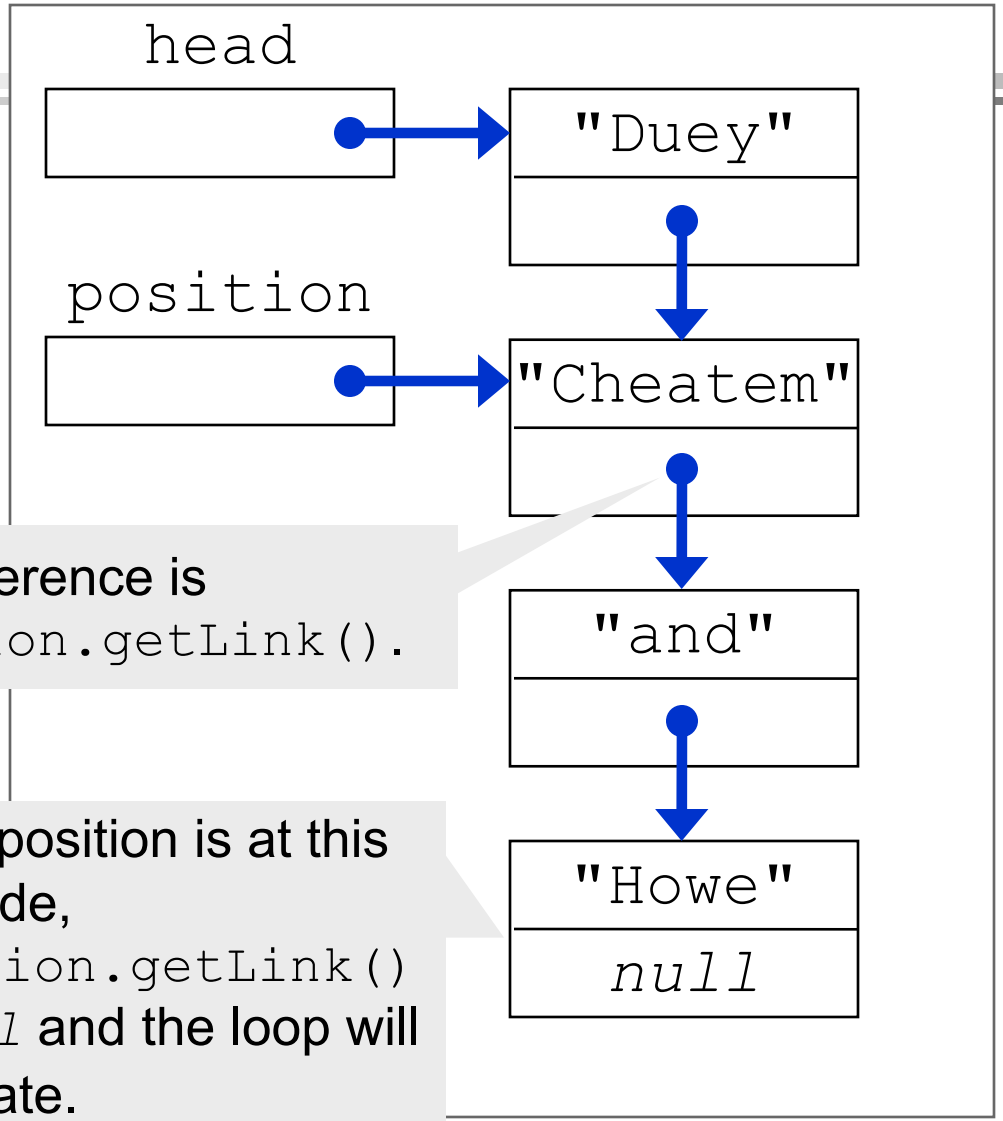
Stepping through a List

Excerpt from `showList` in `StringLinkedList`

Start at beginning of list

```
ListNode position;
position = head;
while (position != null)
{
   ...
   position =
     position.getLink();
}
```

Moves to next node in the list.



This reference is `position.getLink()`.

When position is at this last node, `position.getLink()` is *null* and the loop will terminate.

Adding a Node

To add a node at the beginning of the list:

```
public void addANodeToStart(String addData)
{
   head = new ListNode(addData, head);
}
```

- The new node will point to the old start of the list, which is what `head` pointed to.
- The value of `head` is changed to point to the new node, which is now the first node in the list.

Deleting a Node

To delete a node from the beginning of the list:

```
public void deleteHeadNode()
{
   if (head != null)
   {
      head = head.getLink();
   }
   else
        // prints an error message and exits
...
```

- Doesn't try to delete from an empty list.
- Removes first element and sets head to point to the node that was second but is now first.

Gotcha: Null Pointer Exception

- A Null pointer exception occurs when your code tries to access some class variable and the class variable does not name an object.
- List nodes use `null` to indicate that a link instance variable contains no reference.
- `NullPointerException` is not an exception that has to be caught or declared.
  - » Usually indicates you need to fix your code, not add a `catch` block.

Node Inner Classes

```
public class StringLinkedList
{
    private ListNode head;
        <methods for StringLinkedList inserted here>

    private class ListNode
    {
        <Define ListNode instance variables and methods here>
    }
}
```

- Using an inner class makes `StringLinkedList` self-contained because it doesn't depend on a separate file
- Making the inner class private makes it safer from the point of view of information hiding

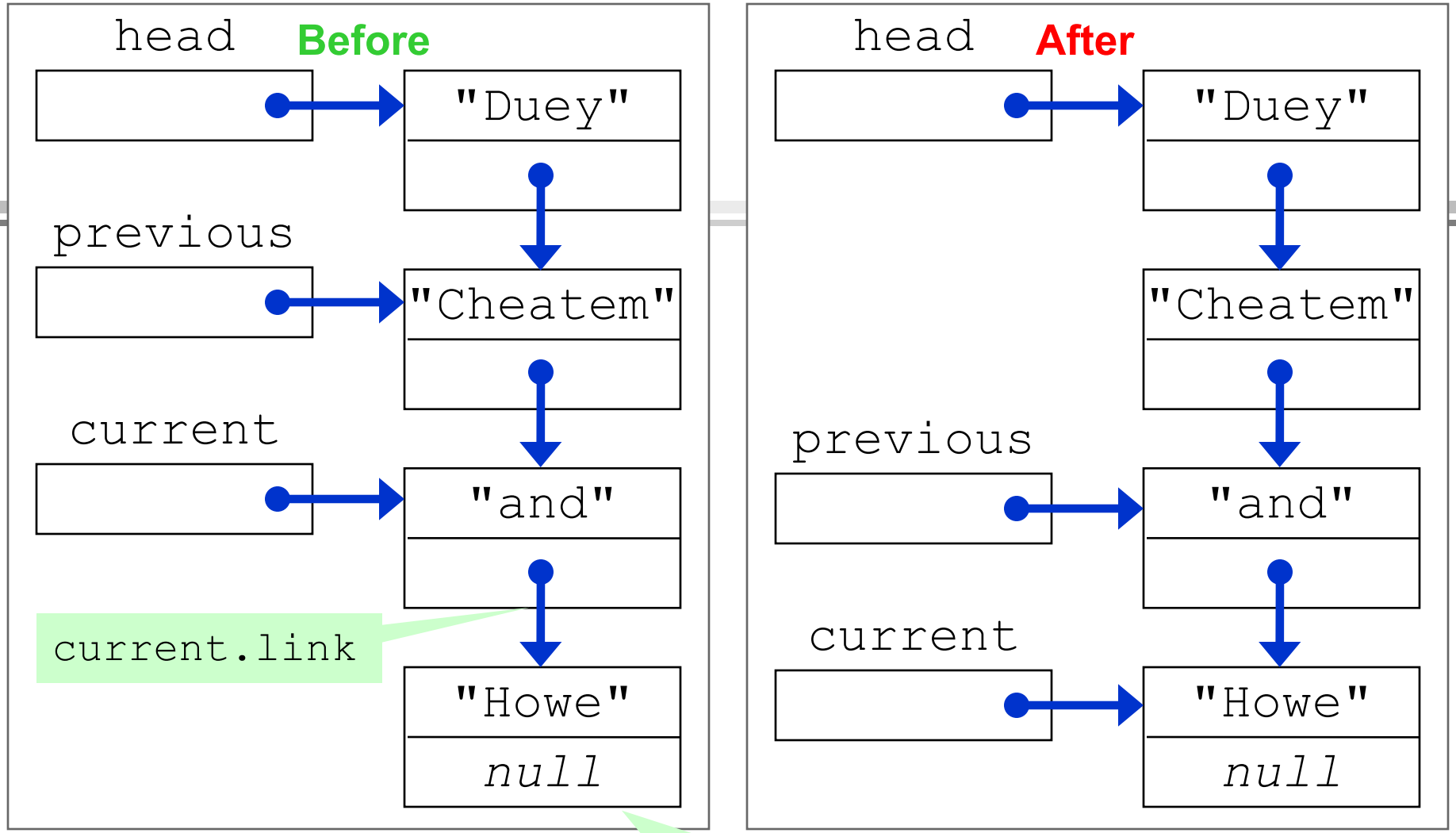
Iterators

- An object that allows a program to step through a collection of objects and do some action on each one is called an ***iterator***.
- For arrays, an index variable can be used as an iterator, with the action of going to the next thing in the list being something like:

```
index++;
```

- In a linked list, a reference to the node can be used as an iterator.
- `StringLinkedListSelfContained` has an instance variable called `current` that is used to keep track of where the iteration is.
- The `goToNext` method moves to the next node in the list by using the statement:

```
current = current.link;
```



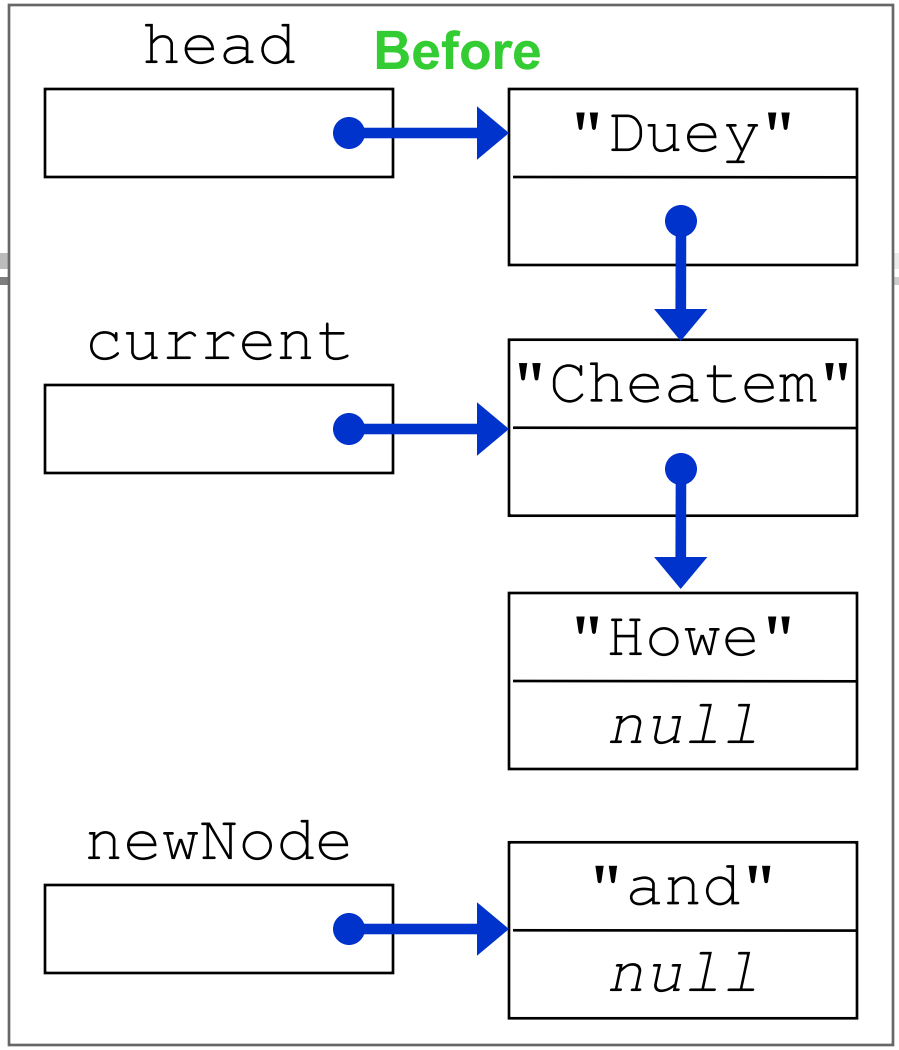
goToNext

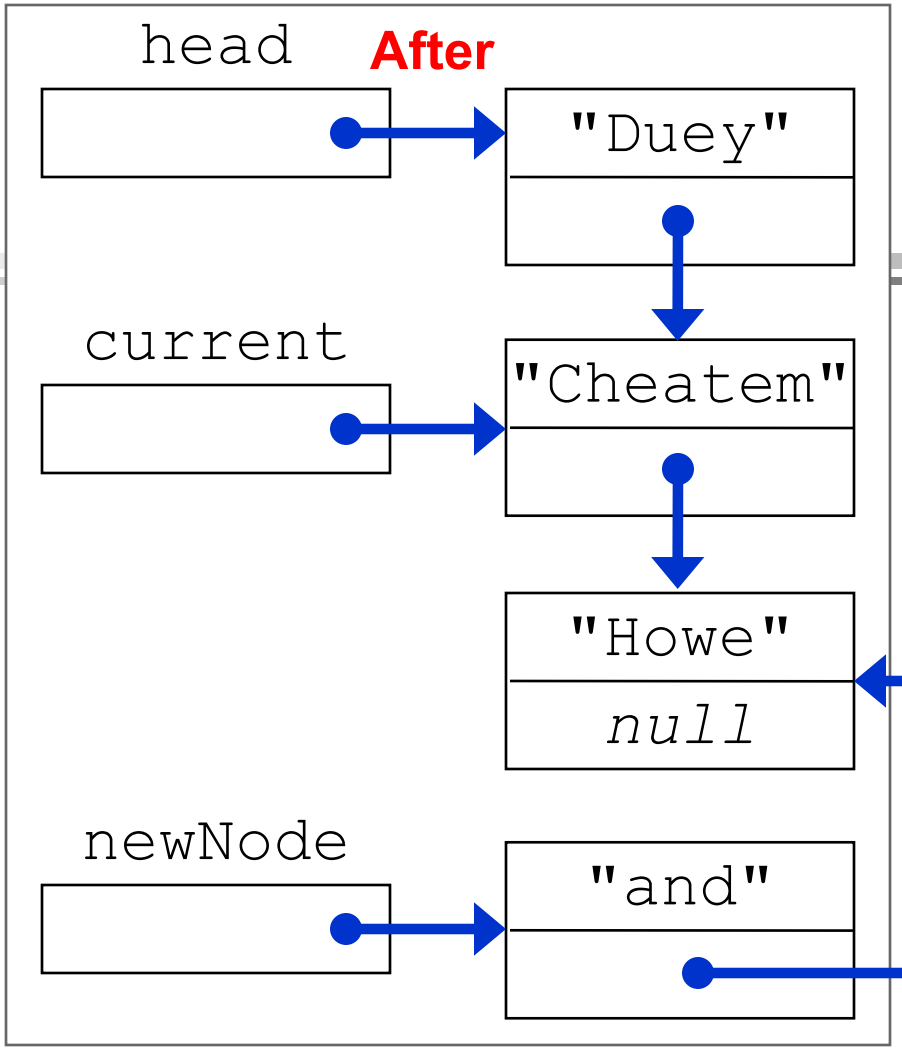
`current = current.link` gives `current` a reference to this node

Other Methods in the Linked List with Iterator

- `getDataAtCurrent()`—returns the data part of the node that the iterator (`current`) is at
- `moreToIterate()`—returns a `boolean` value that will be true if the iterator is not at the end of the list
- `resetIteration()`—moves the iterator to the beginning of the list

- Can write methods to add and delete nodes at the iterator instead of only at the head of the list.
  - » Following slides show diagrams illustrating the add and delete methods.





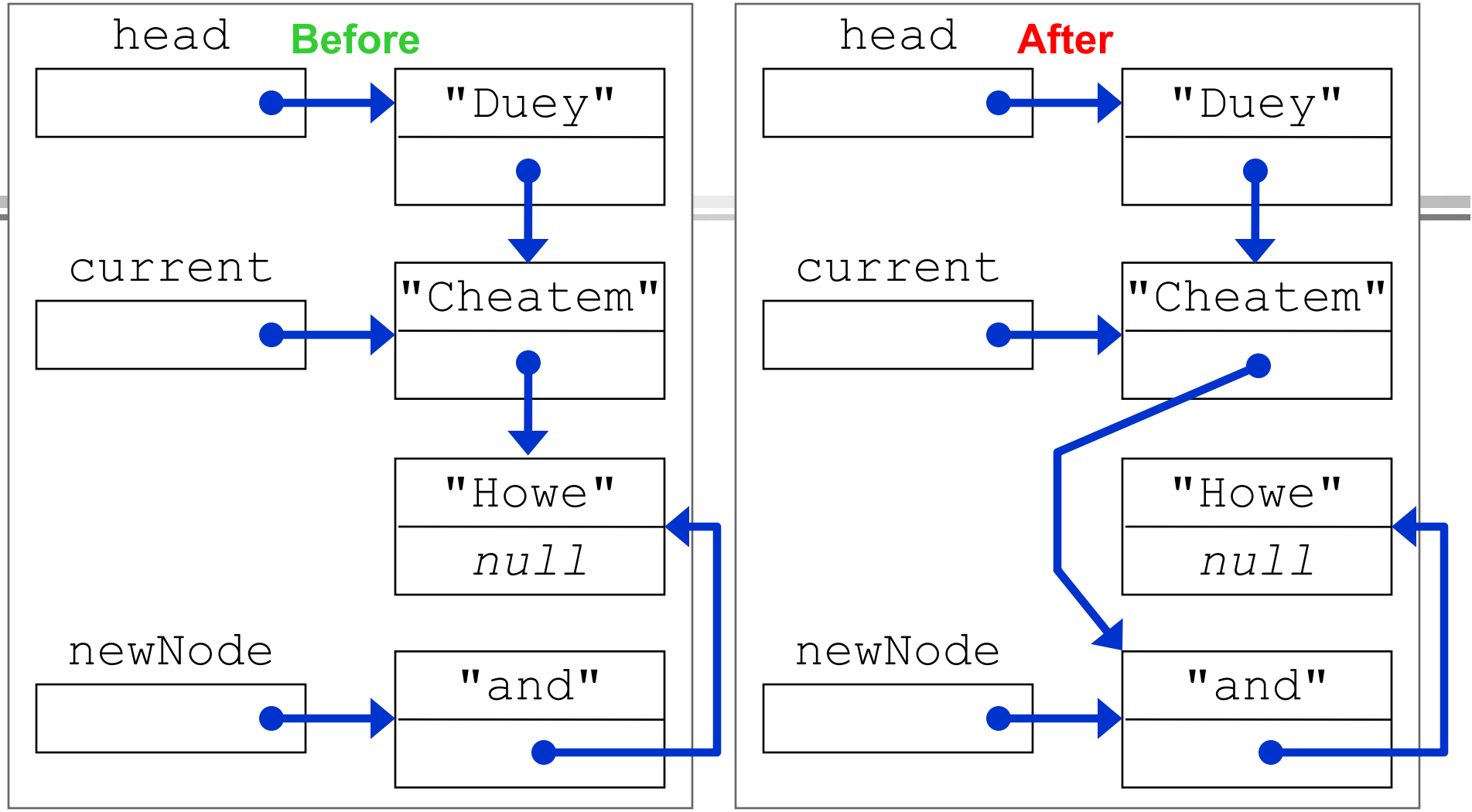
Adding a Node

Step 1

Create the node with reference `newNode`

Add data to the node

```
newNode.link = current.link
```



Adding a Node

Step 2

```
current.link = newNode
```

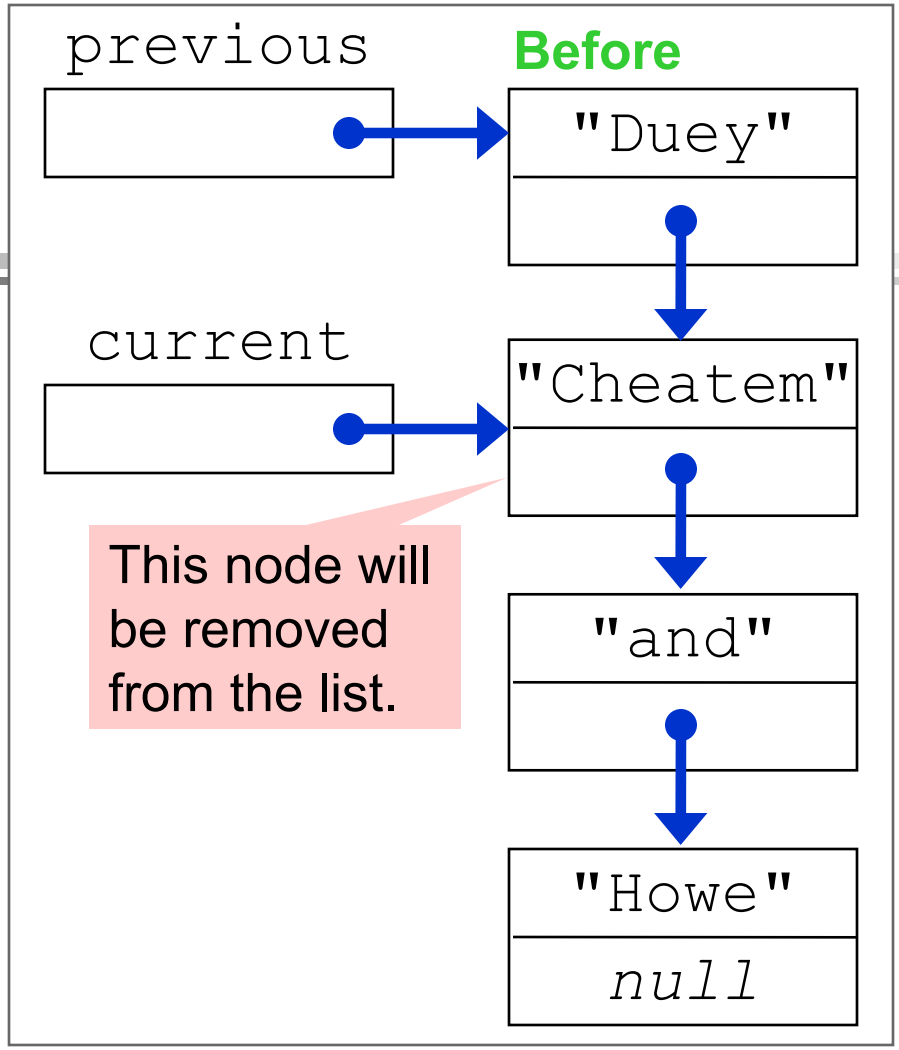
The node has been added to the list although it might appear out of place in this diagram.

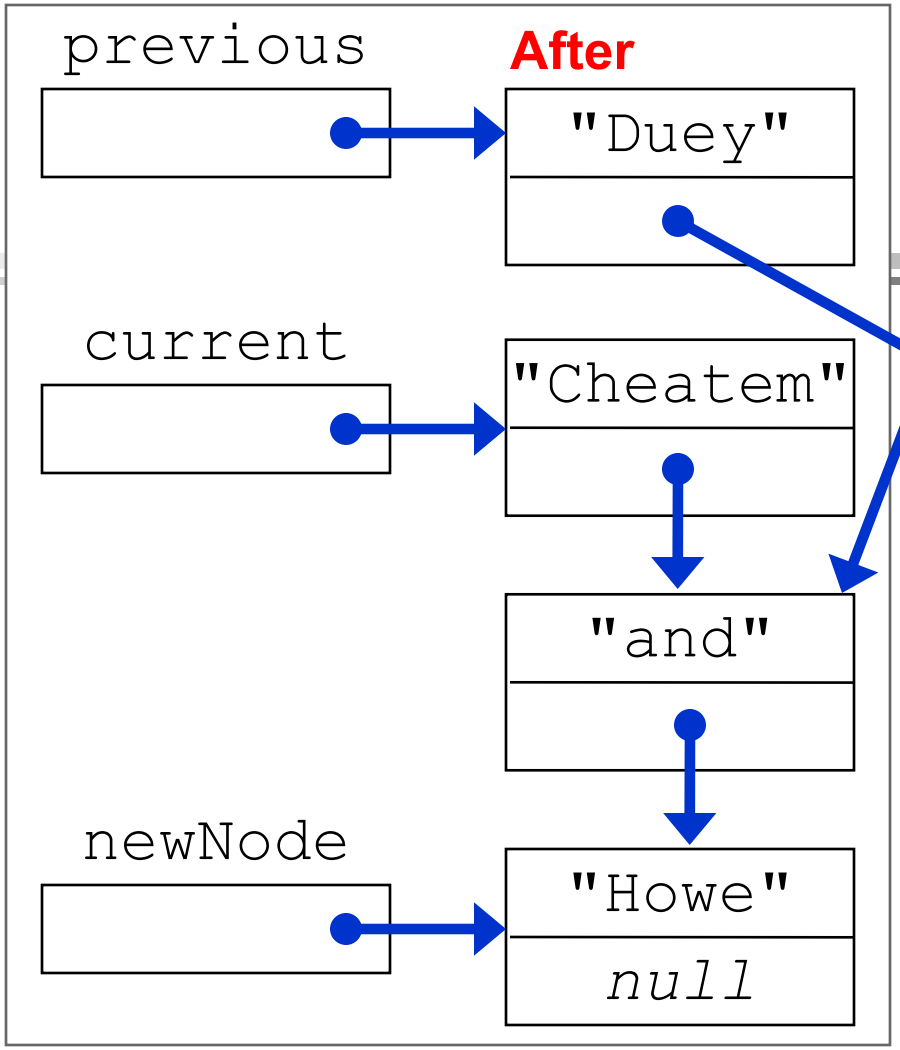
Adding a Node

- After creating the node, the two statements used to add the node to the list are:

```
newNode.link = current.link;
current.link = newNode;
```

- What would happen if these two steps were done in reverse order?



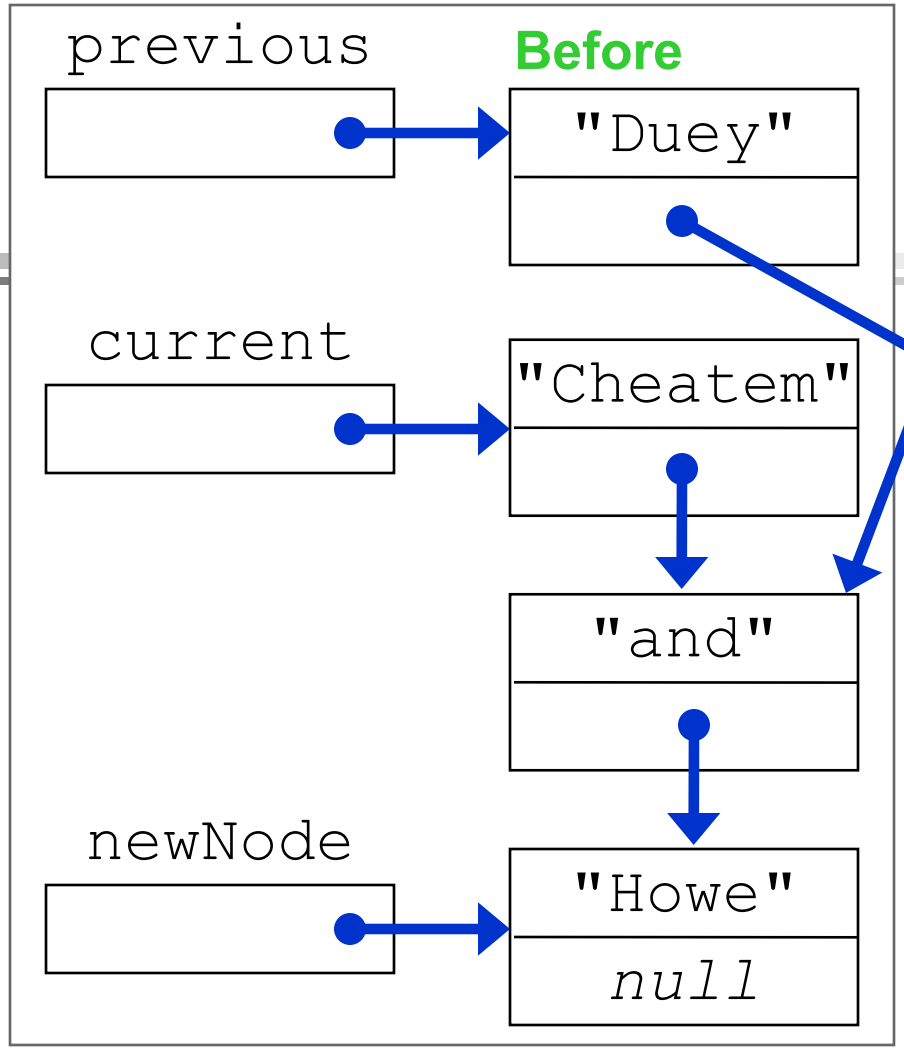


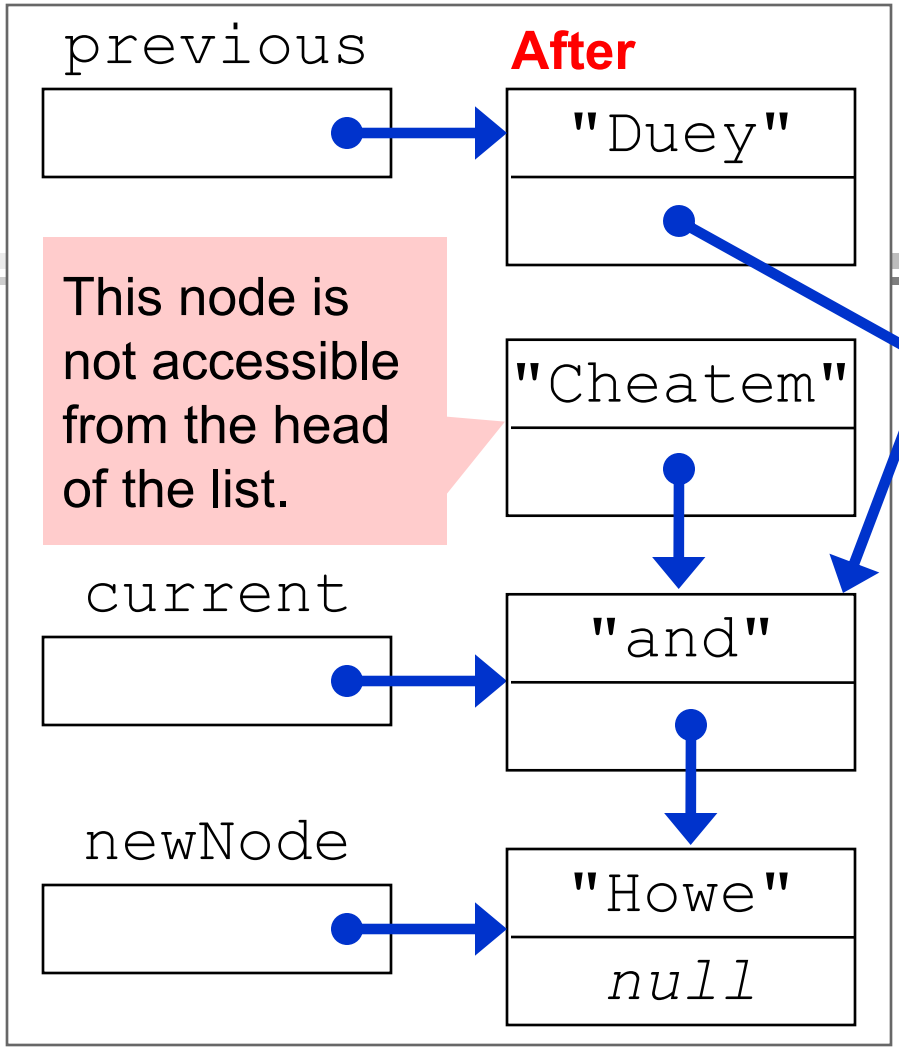
Deleting a Node

Step 1

`previous.link = current.link`

What should be done next?





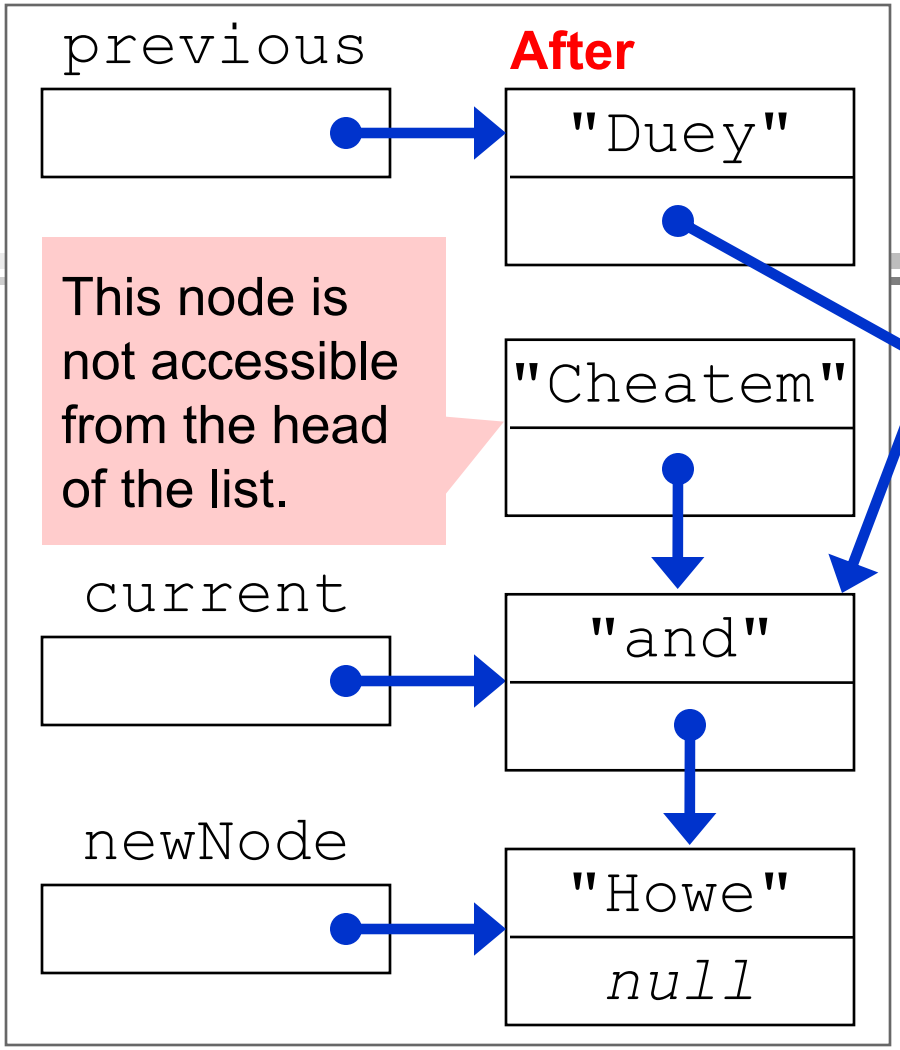
Deleting a Node

Step 2

```
current = current.link
```

The node has been deleted from the list although it is still shown in this picture.

FAQ: What Happens to a Deleted Node?



- The `Cheatem` node has been deleted from the list.
- If there are no other references to the deleted node, the storage should be released for other uses.
  - » Some programming languages make the programmer responsible for ***garbage collection***.
  - » Java provides ***automatic garbage collection***.

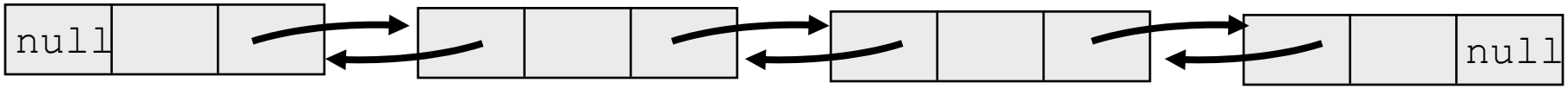
  Storage used by the `Cheatem` node will be available for other uses without the programmer having to do anything.

A Doubly Linked List

- A doubly linked list allows the program to move backward as well as forward in the list.
- The beginning of the node class for a doubly-linked list would look something like this:

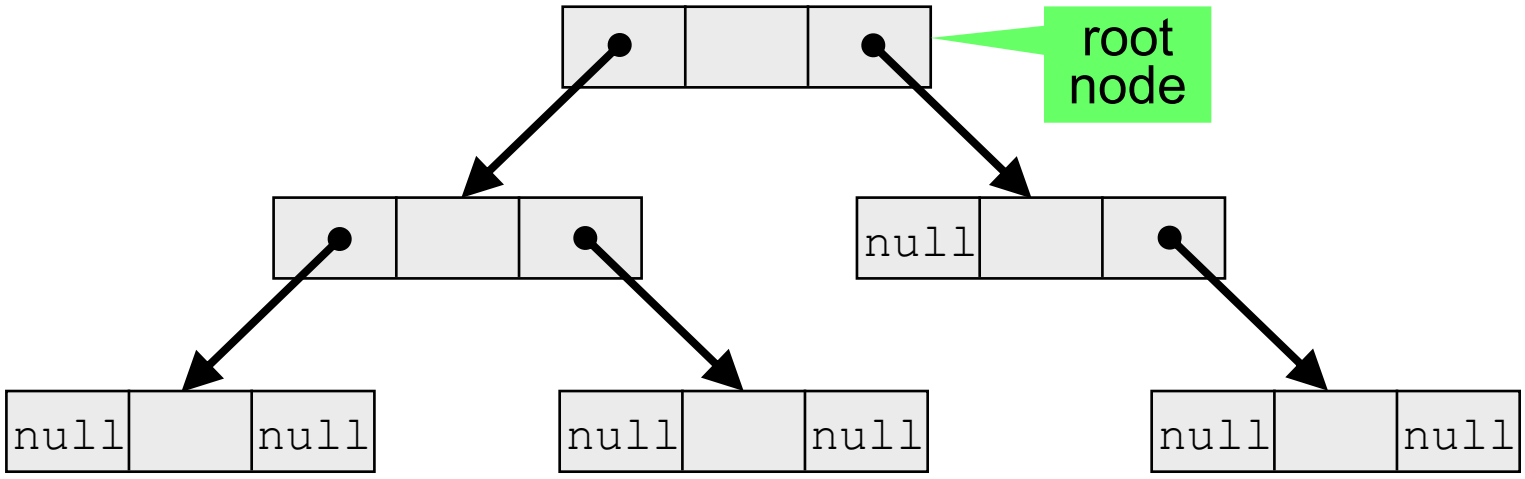
```
private class ListNode
{
    private Object data
    private ListNode next;
    private ListNode previous;
```

Declaring the data reference as class `Object` allows any kind of data to be stored in the list.



Other Linked Data Structures

- ***tree*** data structure
  - » each node leads to multiple other nodes
- ***binary tree***
  - » each node leads to at most two other nodes
- ***root***—top node of tree
  - » normally keep a reference to root, as for head node of list



Summary

- Vectors can be thought of as arrays that can grow in length as needed during run time.
- The base type of all vectors is `Object`.
- Thus, vector elements can be of any class type, but not primitive types.
- A linked list is a data structure consisting of objects known as nodes, such that each node can contain data, and each node has a reference to the next node in the list.
- You can make a linked list self-contained by making the node class an inner class of the linked list class.
- You can use an iterator to step through the elements of a collection.