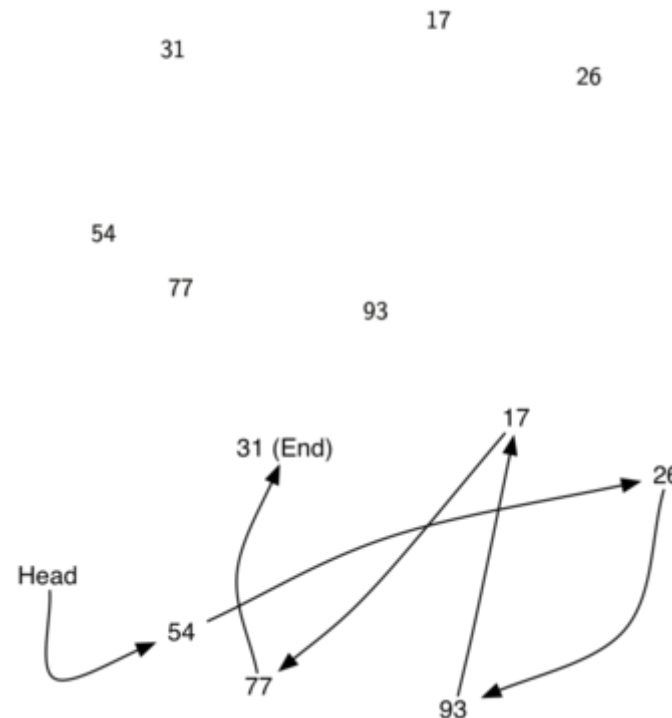


3.21. Implementing an Unordered List: Linked Lists

In order to implement an unordered list, we will construct what is commonly known as a **linked list**. Recall that we need to be sure that we can maintain the relative positioning of the items. However, there is no requirement that we maintain that positioning in contiguous memory. For example, consider the collection of items shown in Figure 1. It appears that these values have been placed randomly. If we can maintain some explicit information in each item, namely the location of the next item (see Figure 2), then the relative position of each item can be expressed by simply following the link from one item to the next.



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It is important to note that the location of the first item of the list must be explicitly specified. Once we know where the first item is, the first item can tell us where the second is, and so on. The external reference is often referred to as the **head** of the list. Similarly, the last item needs to know that there is no next item.

3.21.1. The Node Class

The basic building block for the linked list implementation is the **node**. Each node object must hold at least two pieces of information. First, the node must contain the list item itself. We will call this the **data field** of the node. In addition, each node must hold a reference to the next node. Listing 1 shows the Python implementation. To construct a node, you need to supply the initial data value for the node. Evaluating the assignment statement below will yield a node object containing the value 93 (see Figure 3). You should note that we will typically represent a node object as shown in Figure 4. The `Node` class also includes the usual methods to access and modify the data and the next reference.

Listing 1

```
class Node:
    def __init__(self, initdata):
        self.data = initdata
        self.next = None

    def getData(self):
        return self.data

    def getNext(self):
        return self.next

    def setData(self, newdata):
        self.data = newdata

    def setNext(self, newnext):
        self.next = newnext
```

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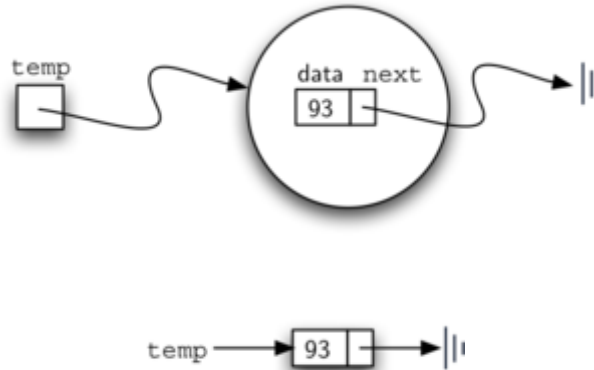
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We create `Node` objects in the usual way.

```
>>> temp = Node(93)
>>> temp.getData()
93
```

The special Python reference value `None` will play an important role in the `Node` class and later in the linked list itself. A reference to `None` will denote the fact that there is no next node. Note in the constructor that a node is initially created with `next` set to `None`. Since this is sometimes referred to as “grounding the node,” we will use the standard ground symbol to denote a reference that is referring to `None`. It is always a good idea to explicitly assign `None` to your initial next reference values.



3.21.2. The Unordered List Class

As we suggested above, the unordered list will be built from a collection of nodes, each linked to the next by explicit references. As long as we know where to find the first node (containing the first item), each item after that can be found by successively following the next links. With this in mind, the `UnorderedList` class must maintain a reference to the first node. Listing 2 shows the constructor. Note that each list object will

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Listing 2

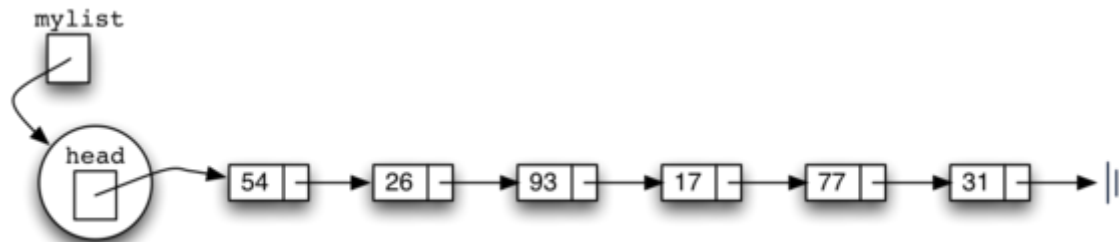
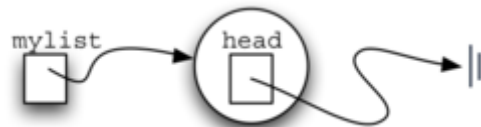
```
class UnorderedList:
```

```
    def __init__(self):  
        self.head = None
```

Initially when we construct a list, there are no items. The assignment statement

```
>>> mylist = UnorderedList()
```

creates the linked list representation shown in Figure 5. As we discussed in the `Node` class, the special reference `None` will again be used to state that the head of the list does not refer to anything. Eventually, the example list given earlier will be represented by a linked list as shown in Figure 6. The head of the list refers to the first node which contains the first item of the list. In turn, that node holds a reference to the next node (the next item) and so on. It is very important to note that the list class itself does not contain any node objects. Instead it contains a single reference to only the first node in the linked structure.



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The `isEmpty` method, shown in Listing 3, simply checks to see if the head of the list is a reference to `None`. The result of the boolean expression `self.head==None` will only be true if there are no nodes in the linked list. Since a new list is empty, the constructor and the check for empty must be consistent with one another. This shows the advantage to using the reference `None` to denote the “end” of the linked structure. In Python, `None` can be compared to any reference. Two references are equal if they both refer to the same object. We will use this often in our remaining methods.

Listing 3

```
def isEmpty(self):  
    return self.head == None
```

So, how do we get items into our list? We need to implement the `add` method. However, before we can do that, we need to address the important question of where in the linked list to place the new item. Since this list is unordered, the specific location of the new item with respect to the other items already in the list is not important. The new item can go anywhere. With that in mind, it makes sense to place the new item in the easiest location possible.

Recall that the linked list structure provides us with only one entry point, the head of the list. All of the other nodes can only be reached by accessing the first node and then following `next` links. This means that the easiest place to add the new node is right at the head, or beginning, of the list. In other words, we will make the new item the first item of the list and the existing items will need to be linked to this new first item so that they follow.

The linked list shown in Figure 6 was built by calling the `add` method a number of times.

```
>>> mylist.add(31)  
>>> mylist.add(77)  
>>> mylist.add(17)  
>>> mylist.add(93)  
>>> mylist.add(26)  
>>> mylist.add(54)
```

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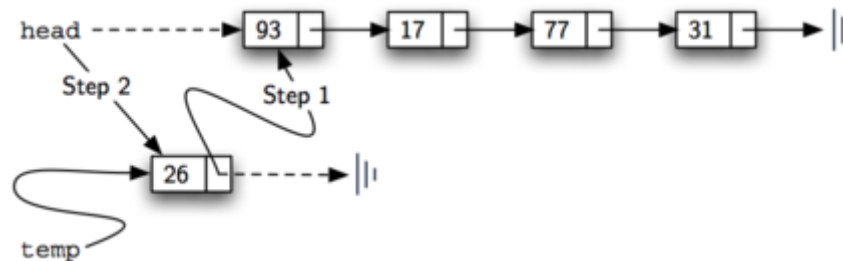
Note that since 31 is the first item added to the list, it will eventually be the last node on the linked list as every other item is added ahead of it. Also, since 54 is the last item added, it will become the data value in the first node of the linked list.

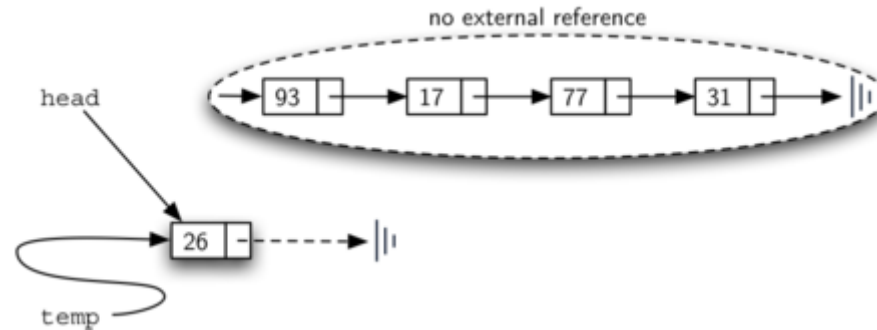
The `add` method is shown in Listing 4. Each item of the list must reside in a node object. Line 2 creates a new node and places the item as its data. Now we must complete the process by linking the new node into the existing structure. This requires two steps as shown in Figure 7. Step 1 (line 3) changes the `next` reference of the new node to refer to the old first node of the list. Now that the rest of the list has been properly attached to the new node, we can modify the head of the list to refer to the new node. The assignment statement in line 4 sets the head of the list.

The order of the two steps described above is very important. What happens if the order of line 3 and line 4 is reversed? If the modification of the head of the list happens first, the result can be seen in Figure 8. Since the head was the only external reference to the list nodes, all of the original nodes are lost and can no longer be accessed.

Listing 4

```
def add(self,item):  
    temp = Node(item)  
    temp.setNext(self.head)  
    self.head = temp
```





The next methods that we will implement— `size` , `search` , and `remove` —are all based on a technique known as **linked list traversal**. Traversal refers to the process of systematically visiting each node. To do this we use an external reference that starts at the first node in the list. As we visit each node, we move the reference to the next node by “traversing” the next reference.

To implement the `size` method, we need to traverse the linked list and keep a count of the number of nodes that occurred. Listing 5 shows the Python code for counting the number of nodes in the list. The external reference is called `current` and is initialized to the head of the list in line 2. At the start of the process we have not seen any nodes so the count is set to 0. Lines 4–6 actually implement the traversal. As long as the current reference has not seen the end of the list (`None`), we move `current` along to the next node via the assignment statement in line 6. Again, the ability to compare a reference to `None` is very useful. Every time `current` moves to a new node, we add 1 to `count` . Finally, `count` gets returned after the iteration stops. Figure 9 shows this process as it proceeds down the list.

Listing 5

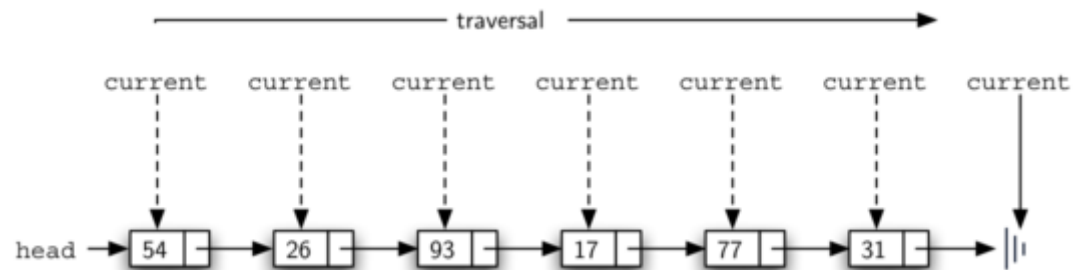
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```

1  def size(self):
2      current = self.head
3      count = 0
4      while current != None:
5          count = count + 1
6          current = current.getNext()
7
8      return count

```



Searching for a value in a linked list implementation of an unordered list also uses the traversal technique. As we visit each node in the linked list we will ask whether the data stored there matches the item we are looking for. In this case, however, we may not have to traverse all the way to the end of the list. In fact, if we do get to the end of the list, that means that the item we are looking for must not be present. Also, if we do find the item, there is no need to continue.

Listing 6 shows the implementation for the `search` method. As in the `size` method, the traversal is initialized to start at the head of the list (line 2). We also use a boolean variable called `found` to remember whether we have located the item we are searching for. Since we have not found the item at the start of the traversal, `found` can be set to `False` (line 3). The iteration in line 4 takes into account both conditions discussed above. As long as there are more nodes to visit and we have not found the item we are looking for, we check the next node. The question in line 5 asks whether the data item (The UnorderedListAbstractDataType.html) is present in the current node. If so, `found` can be set to `True`.

Listing 6


```

1  def search(self,item):
2      current = self.head
3      found = False
4      while current != None and not found:
5          if current.getData() == item:
6              found = True
7          else:
8              current = current.getNext()
9
10     return found

```

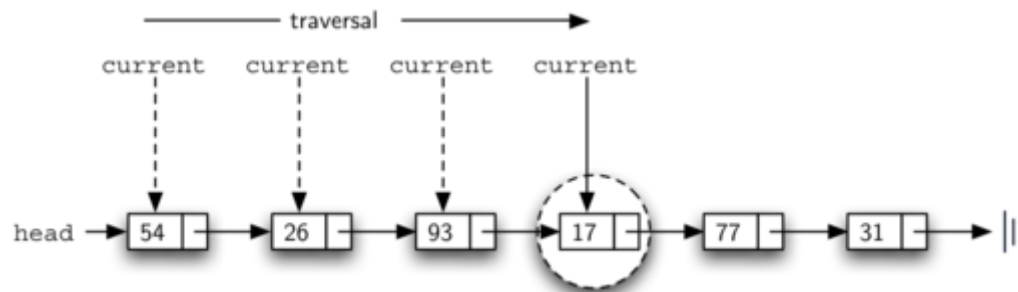
As an example, consider invoking the `search` method looking for the item 17.

```

>>> mylist.search(17)
True

```

Since 17 is in the list, the traversal process needs to move only to the node containing 17. At that point, the variable `found` is set to `True` and the `while` condition will fail, leading to the return value seen above. This process can be seen in Figure 10.



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(TheUnorderedListAbstractDataType.html) requires two logical steps. First, we need to traverse the list looking for the item we want to remove. Once we find the item (recall that we assume it is present), we must remove it. The first step is very similar to `search`. Starting with an external reference set to the head of the list, we traverse the

links until we discover the item we are looking for. Since we assume that item is present, we know that the iteration will stop before `current` gets to `None`. This means that we can simply use the boolean `found` in the condition.

When `found` becomes `True`, `current` will be a reference to the node containing the item to be removed. But how do we remove it? One possibility would be to replace the value of the item with some marker that suggests that the item is no longer present. The problem with this approach is the number of nodes will no longer match the number of items. It would be much better to remove the item by removing the entire node.

In order to remove the node containing the item, we need to modify the link in the previous node so that it refers to the node that comes after `current`. Unfortunately, there is no way to go backward in the linked list. Since `current` refers to the node ahead of the node where we would like to make the change, it is too late to make the necessary modification.

The solution to this dilemma is to use two external references as we traverse down the linked list. `current` will behave just as it did before, marking the current location of the traverse. The new reference, which we will call `previous`, will always travel one node behind `current`. That way, when `current` stops at the node to be removed, `previous` will be referring to the proper place in the linked list for the modification.

Listing 7 shows the complete `remove` method. Lines 2–3 assign initial values to the two references. Note that `current` starts out at the list head as in the other traversal examples. `previous`, however, is assumed to always travel one node behind `current`. For this reason, `previous` starts out with a value of `None` since there is no node before the head (see Figure 11). The boolean variable `found` will again be used to control the iteration.

In lines 6–7 we ask whether the item stored in the current node is the item we wish to remove. If so, `found` can be set to `True`. If we do not find the item, `previous` and `current` must both be moved one node ahead. Again, the order of these two statements is crucial. `previous` must first be moved one node ahead to the location of `current`. At that point, `current` can be moved. This process is often referred to as “inch-worming” as `previous` must catch up to `current` before `current` moves ahead. Figure 12 shows the movement of `previous` and `current` as they progress down the list looking for the node containing the

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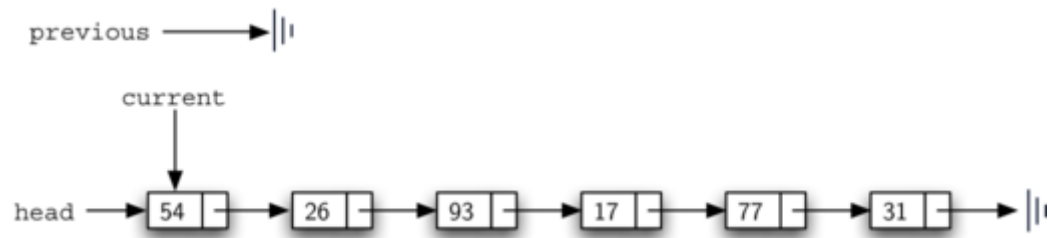
Listing 7

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```

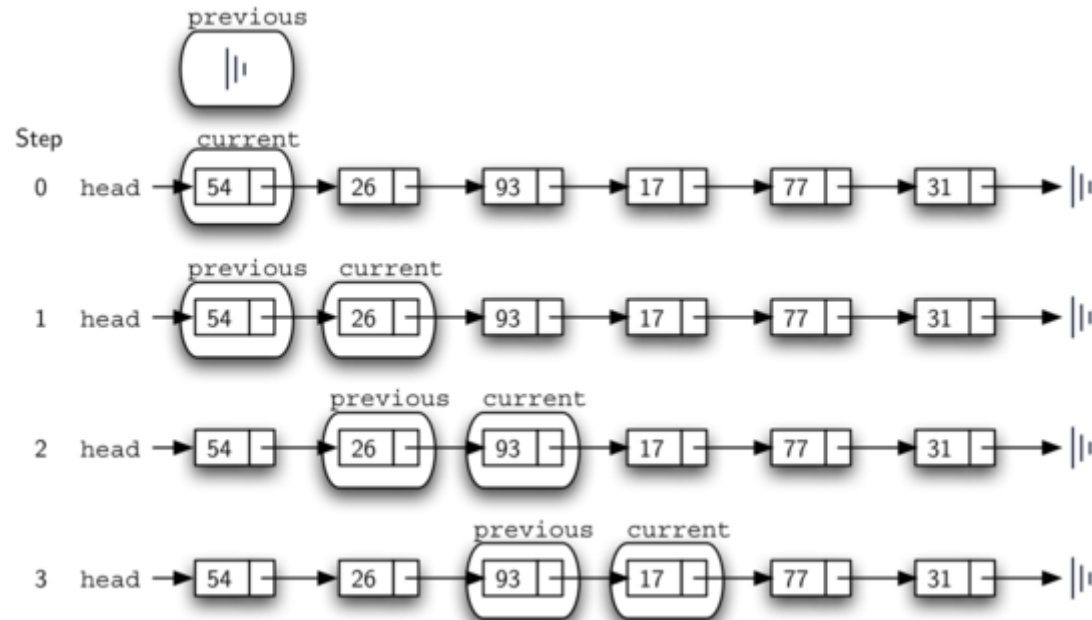
1  def remove(self,item):
2      current = self.head
3      previous = None
4      found = False
5      while not found:
6          if current.getData() == item:
7              found = True
8          else:
9              previous = current
10             current = current.getNext()
11
12     if previous == None:
13         self.head = current.getNext()
14     else:
15         previous.setNext(current.getNext())

```

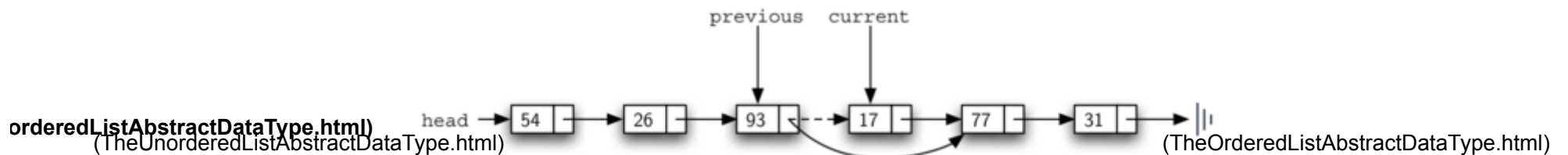


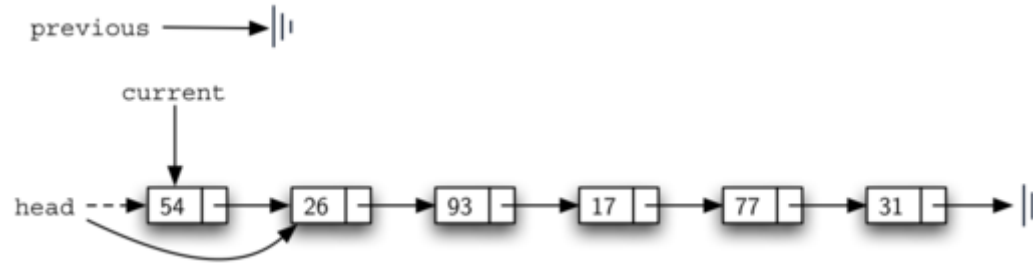
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Once the searching step of the `remove` has been completed, we need to remove the node from the linked list. Figure 13 shows the link that must be modified. However, there is a special case that needs to be addressed. If the item to be removed happens to be the first item in the list, then `current` will reference the first node in the linked list. This also means that `previous` will be `None`. We said earlier that `previous` would be referring to the node whose next reference needs to be modified in order to complete the remove. In this case, it is not `previous` but rather the `head` of the list that needs to be changed (see Figure 14).





Line 12 allows us to check whether we are dealing with the special case described above. If `previous` did not move, it will still have the value `None` when the boolean `found` becomes `True`. In that case (line 13) the head of the list is modified to refer to the node after the current node, in effect removing the first node from the linked list. However, if `previous` is not `None`, the node to be removed is somewhere down the linked list structure. In this case the `previous` reference is providing us with the node whose next reference must be changed. Line 15 uses the `setNext` method from `previous` to accomplish the removal. Note that in both cases the destination of the reference change is `current.getNext()`. One question that often arises is whether the two cases shown here will also handle the situation where the item to be removed is in the last node of the linked list. We leave that for you to consider.

You can try out the `UnorderedList` class in ActiveCode 1.

Run

Show Code

ActiveCode: 1 The Complete UnorderedList Class (unorderedlistcomplete)

The remaining methods `append`, `insert`, `index`, and `pop` are left as exercises. Remember that each of these must take into account whether the change is taking place at the head of the list or someplace else.

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Also, `insert`, `index`, and `pop` require that we name the positions of the list. We will assume that position names are integers starting with 0.

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Self Check

Part I: Implement the append method for UnorderedList. What is the time complexity of the method you created?

Run

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Show Code

Code Coach

ActiveCode: 2 (self_check_list1)

Part II: In the previous problem, you most likely created an append method that was $O(n)$. If you add an instance variable to the UnorderedList class you can create an append method that is $O(1)$. Modify your append method to be $O(1)$. Be Careful! To really do this correctly you will need to consider a couple of special cases that may require you to make a modification to the add method as well.

Run

Show Feedback

Show Code

Code Coach

ActiveCode: 3 (self_check_list2)

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