CMPUT 175
Introduction to Foundations of Computing

Singly-Linked List and Doubly-Linked List

Objectives

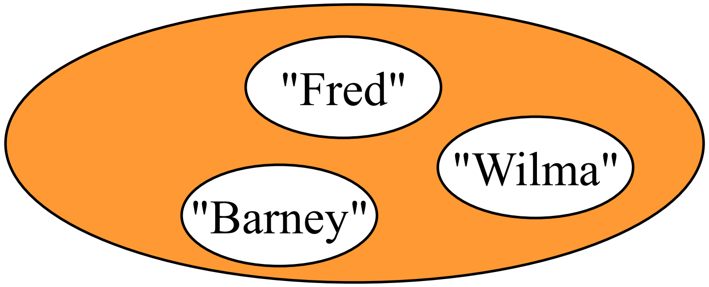
- In this lecture we will learn about an implementation of Lists called Singly-Linked List
- We will first draw lists and discuss them.
- We will create a class for elements of a list then a class for the list itself.
- We will repeat the process for a Doubly-Linked List

Why the need for a new ADT?

- We piggy backed on the List to implement our Stack and our Queue.
- We don't really know how the list is implemented in Python
- We are actually lucky that Python provides a List. Many programming languages do not provide such a data structure.
- When data structures store information in consecutive memory locations we have to shift items around to add space in between elements or replace a removed element.
- We would like a data structure with the ability to add and remove anywhere in the collection without shifting elements.

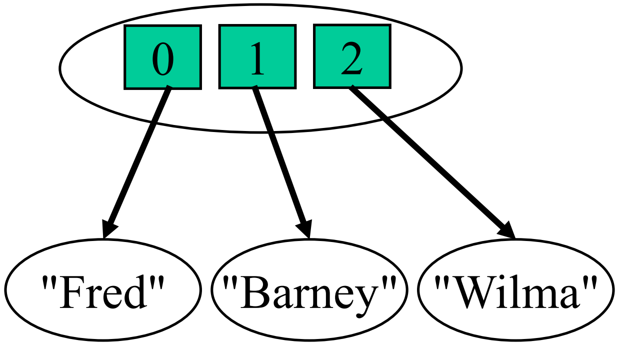
External Container Diagrams

- We can draw an external or implementation-independent diagram of a container by just showing its elements.
- For example, here is the diagram for a general container where the elements are not even ordered:



Indexed Container Diagrams

- We can modify the diagram when the interface is more specific.
- For example, here is a diagram for an indexed container.
- Note that it still might be implemented in different ways

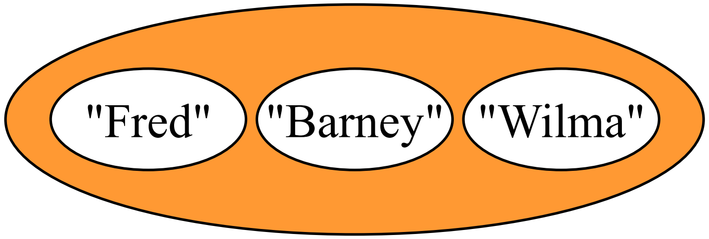


Do you know how a list is implemented in Python?

You only know it is an indexed container. You can append, insert, pop, check length, etc.

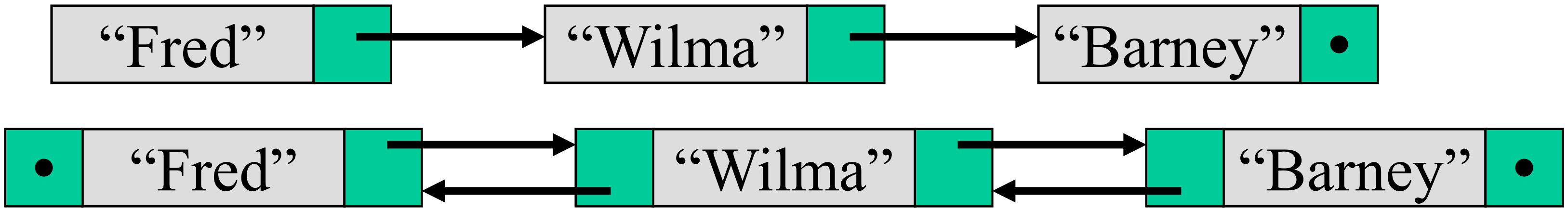
External List Diagrams

- Since the elements in a list are ordered, they must be “connected” somehow to maintain this order.
- Since different implementation classes “connect” the elements differently, we do not show the connections in an external diagram.

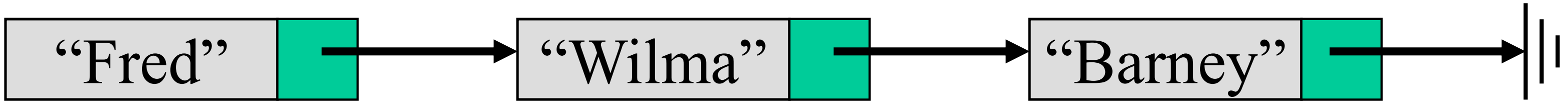


Internal List Diagrams - Nodes

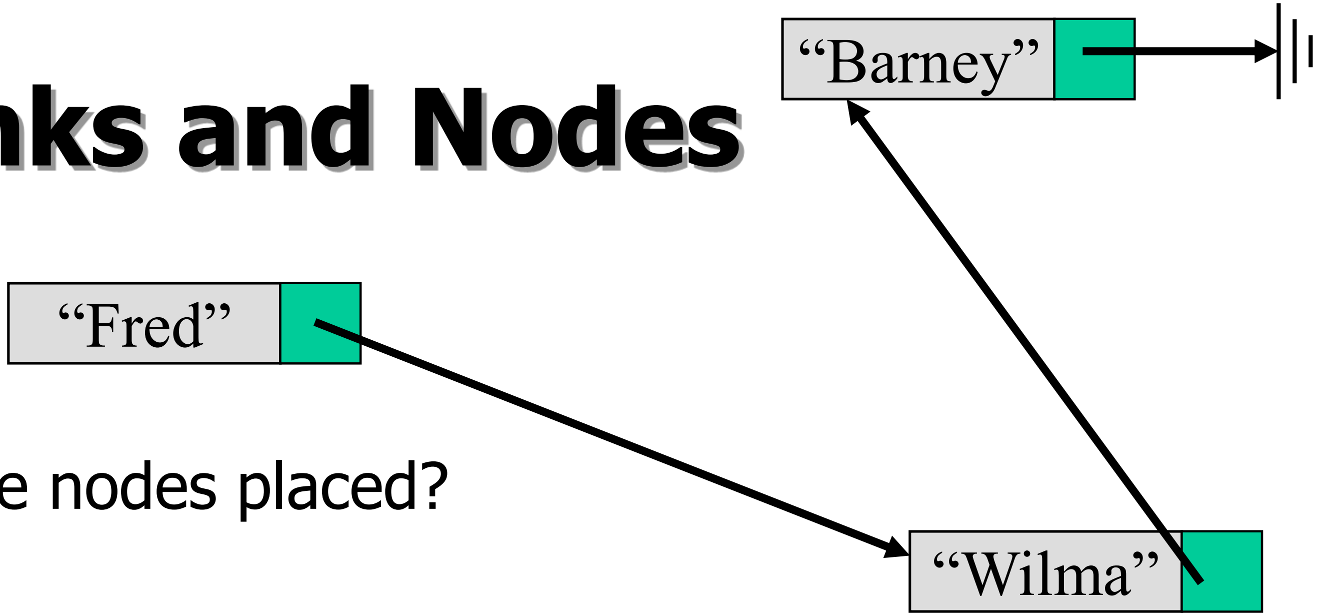
- However, when we want to highlight a particular class implementation of a List, we add internal structure.
- Each element is put in a list **node** and the nodes connect to each other with **links**.
- The end of the list is denoted by a dot instead of a link to another node.



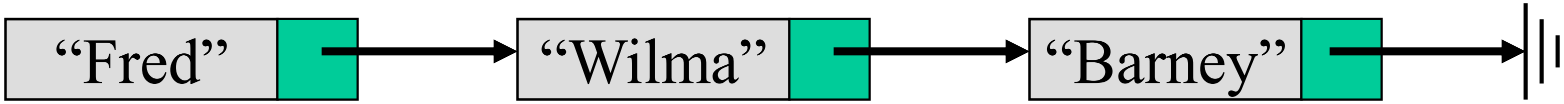
- Instead of a dot, it can be represented as a link going nowhere, sometimes called Nil, Null or None.



Links and Nodes



- Where are these nodes placed?
- What are these links from one node to the other?
- What can the content of these nodes be?



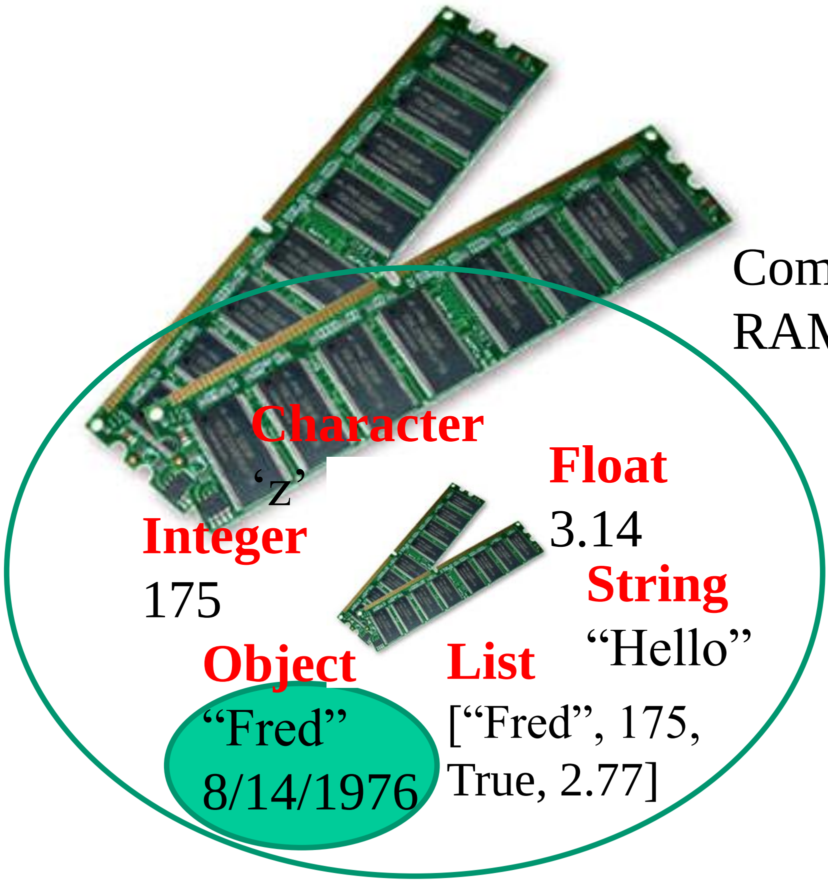
1 Byte = 8 bits = one characters

1 Kilobyte KB = 1024 bytes about 1000 bytes

1 Megabyte MB = about 1000 Kilobyte

1 Gigabyte GB = 1000 MB = about a billion bytes

1 Terabyte TB = 1000 GB



Computer Memory
RAM: Random Access Memory

Character
‘z’

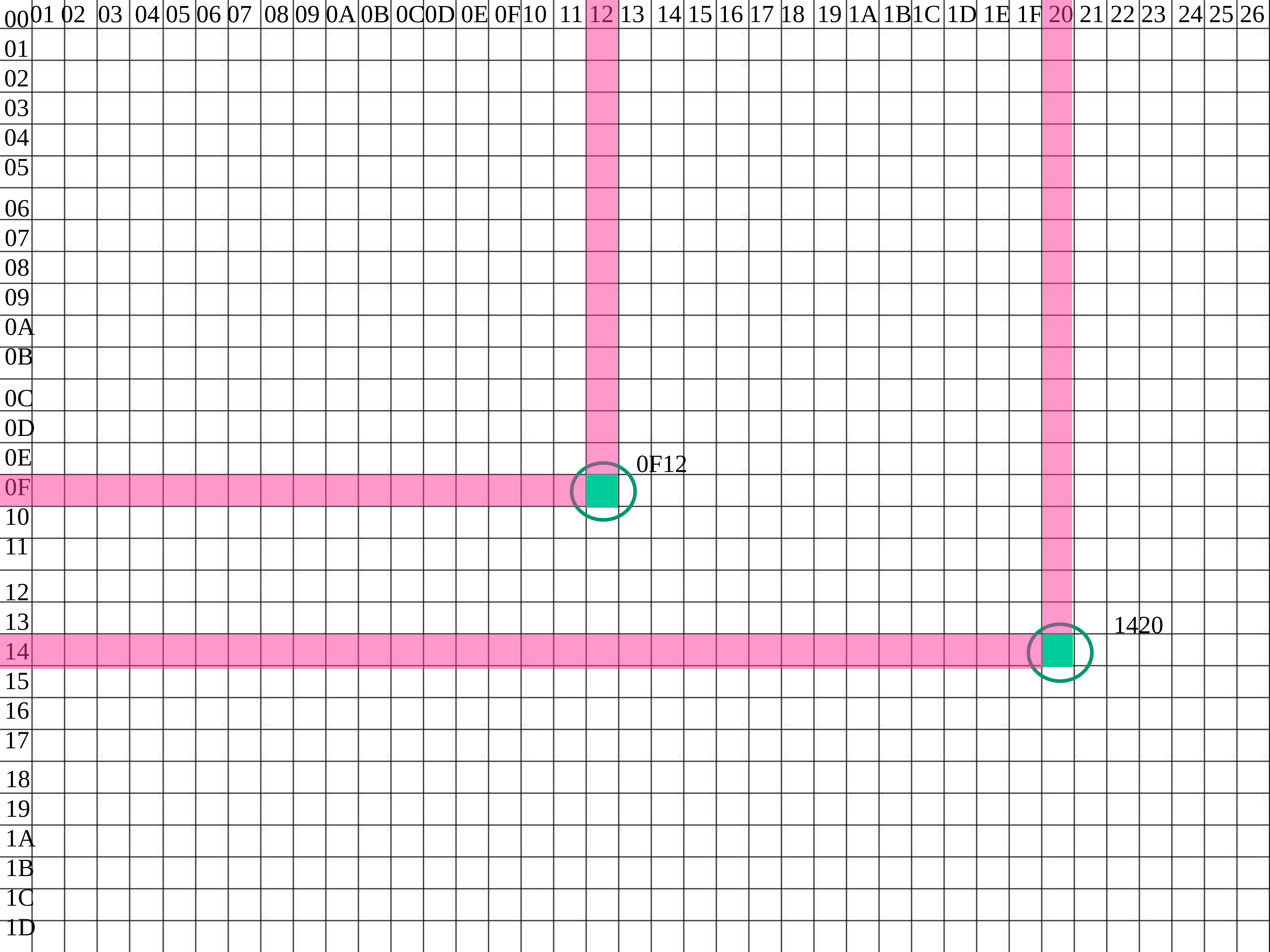
Integer
175

Float
3.14

String
“Hello”

Object
“Fred”
8/14/1976

List
[“Fred”, 175,
True, 2.77]


00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F 10 11 12 13 14 15 16 17 18 19 1A 1B 1C 1D 1E 1F 20 21 22 23 24 25 26
01
02
03
04
05
06
07
08
09
0A
0B
0C
0D
0E
0F
10
11
12
13
14
15
16
17
18
19
1A
1B
1C
1D
0F12
1420

Character

c

Integer

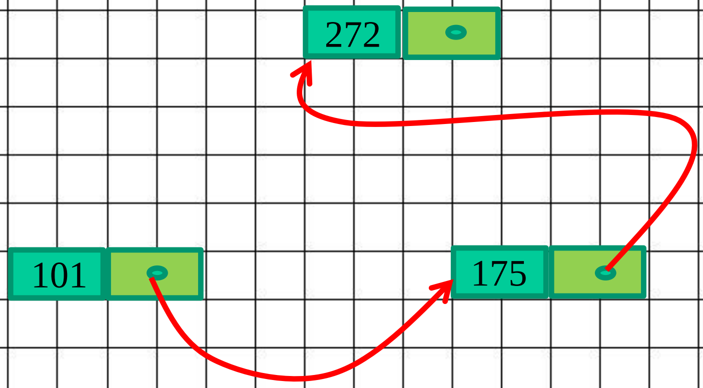
175

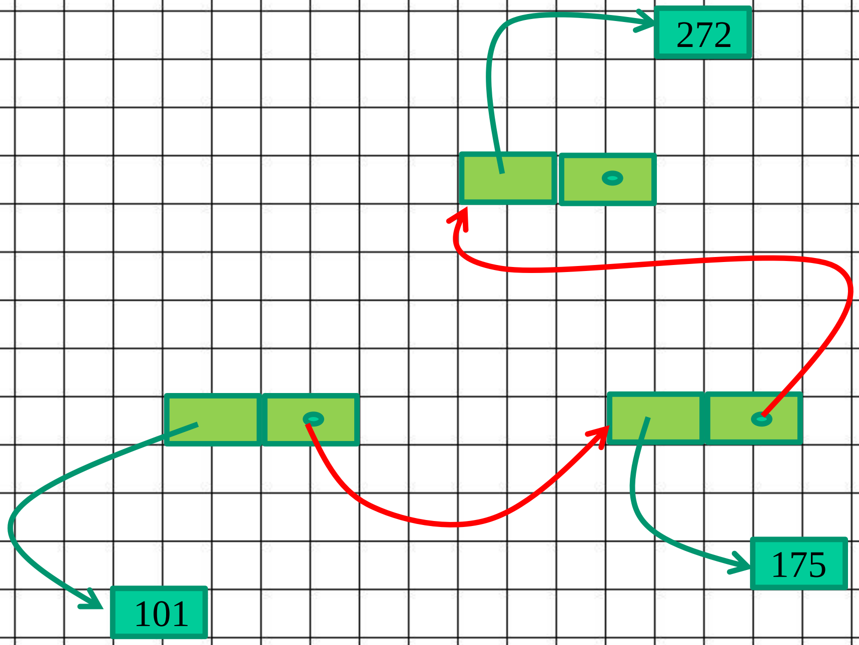
Long Integer

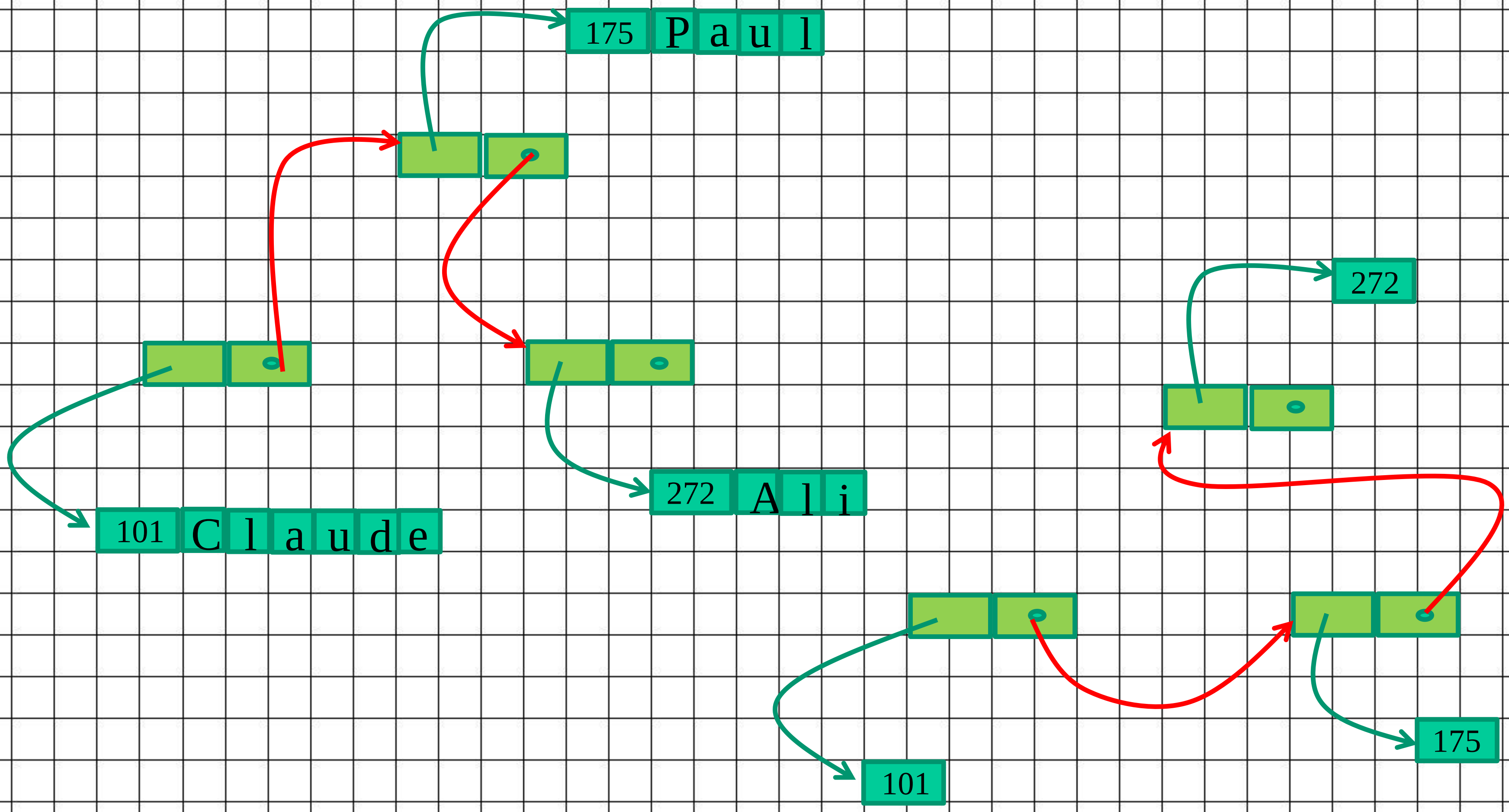
20170301

Array of 10 Integers

101	175	272	?	?	?	?	?	?	?

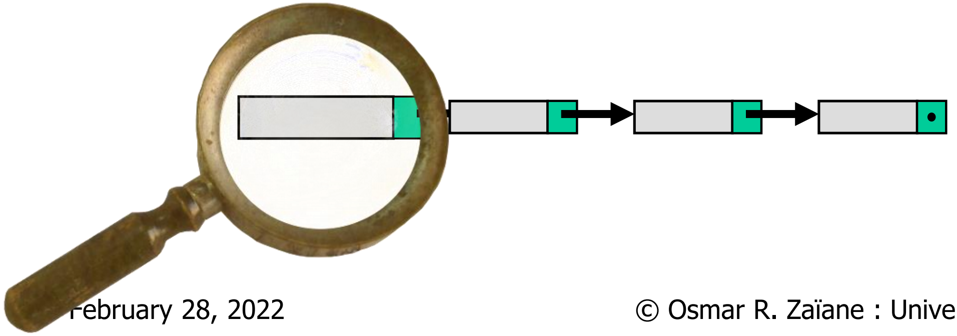


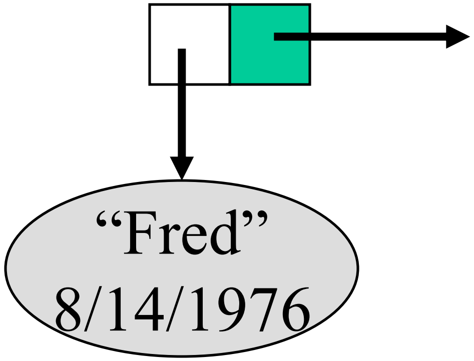



175
Paul
101
Claude
272
Ali
272
101
175

Complex List Node Diagrams

- If the elements of a list are complex objects, it is not always possible to draw the elements inside the node.
- In this case, an arrow is used in the node to represent a reference to the element.
- This diagram is actually more accurate since the node always contains a reference to an object instead of an object.

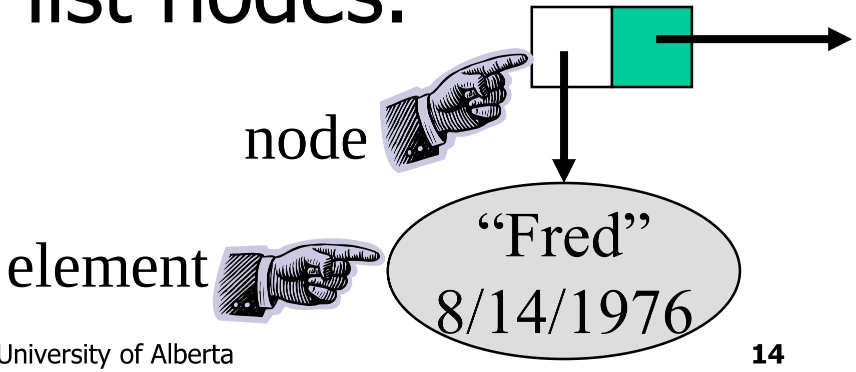


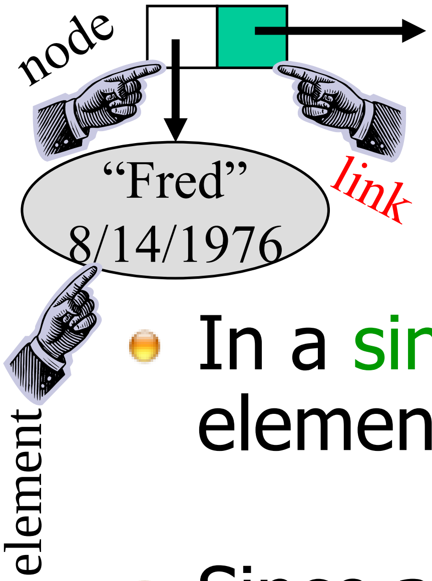


Terminology: Elements & Nodes

- In these notes we use the term **element** to refer to the individual values or objects that collectively make up the list.

- We use the term **node** to refer to an object that contains an element object and links to adjacent list nodes.





Singly-Linked Lists

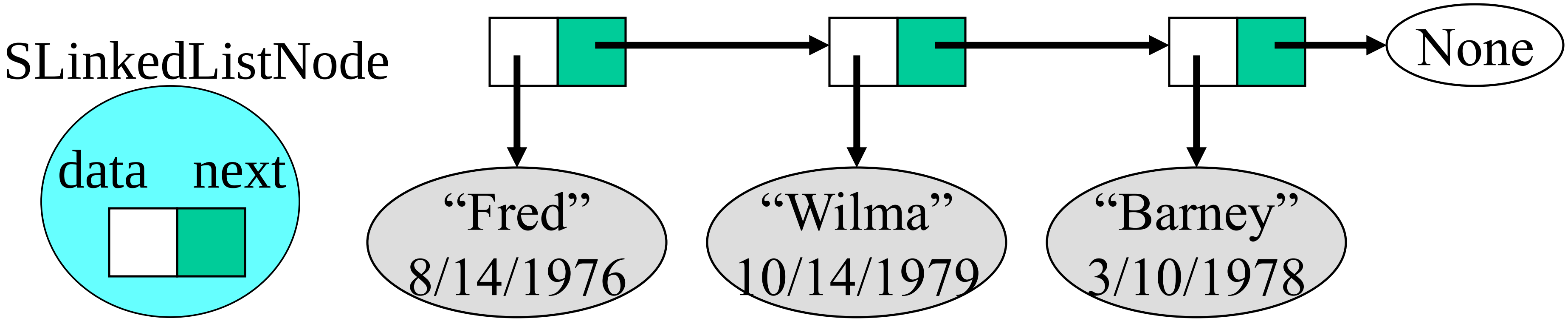
- In a singly-linked list, each list node contains an element and a link to the "next" node in the list.

- Since a node contains a link to the next node, this is an example of self-referencing of objects. It points to another instance of the same class.

- We need to define two classes to implement a singly-linked list: one for the nodes and one for the list itself.
- We will call the first one **SLinkedListNode** and the second **SLinkedList**

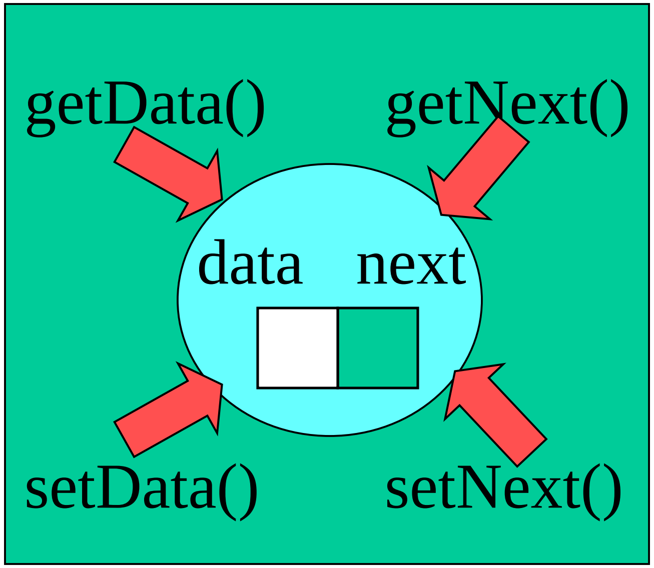
SLinkedListNode Class

- Each instance of SLinkedListNode represents a single list node with two instance variables.
- The instance variable, data, is a reference to an element object.
- The instance variable, next, is a reference to the next node (another instance of SLinkedListNode) or None if it is the last node (tail node).



Interface for ADT Node

- setData(element) set element as the new data
- setNext(reference) set reference as the new next
- getData() returns the data element
- getNext() returns the reference to the next node



SLinkedListNode in Python

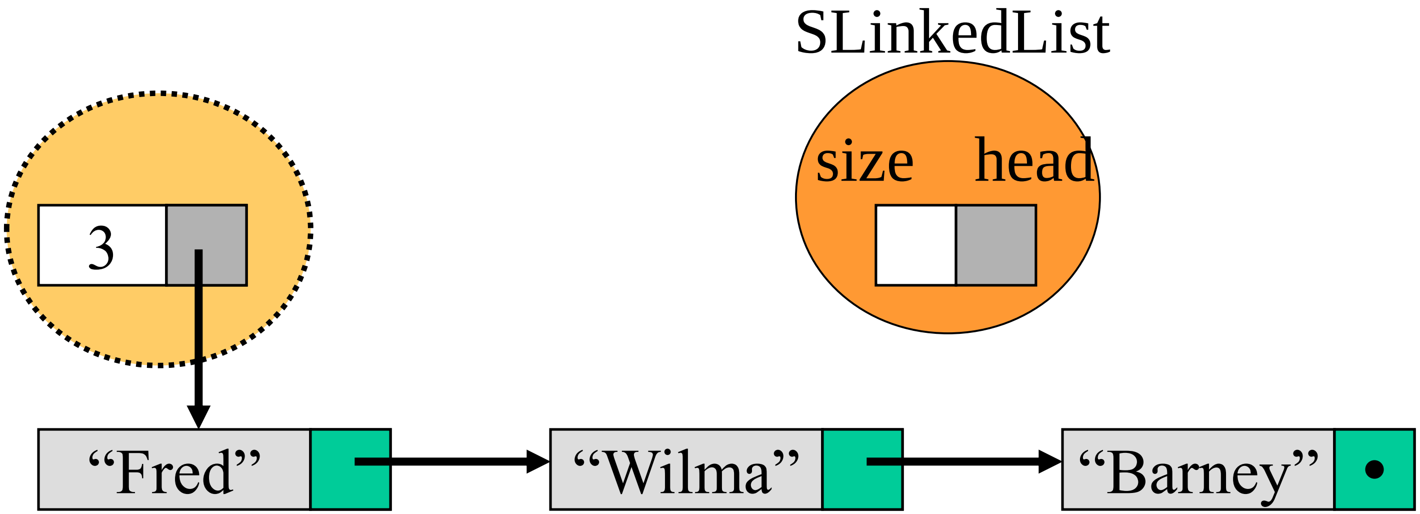
```python
class SLinkedListNode:
    def __init__(self, initData, initNext):
    # constructs a new node and initializes it to contain
    # the given object (initData) and link to the given next node.

        self.data = initData
        self.next = initNext


    def getData(self): # returns the element
        return self.data

    def getNext(self): # returns the next node
        return self.next

    def setData(self, newData): # sets the newData as the element
        self.data = newData

    def setNext(self, newNext): # sets the newNext as the next node
        self.next= newNext
```

Interface for ADT List

add(item)	adds a new item to the list
remove(item)	removes the item from the list
search(item)	returns a boolean value if item in list
isEmpty()	tests to see whether the list is empty
length()	returns the number of elements in the list
append(item)	adds item to the end of list
index(item)	returns the position of item in the list
insert(pos,item)	adds an item at a given position in list
pop()	removes and returns the last item
pop(pos)	removes and returns the item at a position

SLinkedList Class

- Each SLinkedList object has an instance variable, head, that is a reference to the first SLinkedListNode object of the list.
- It also maintains an integer valued instance variable, size, that is the size of the list.

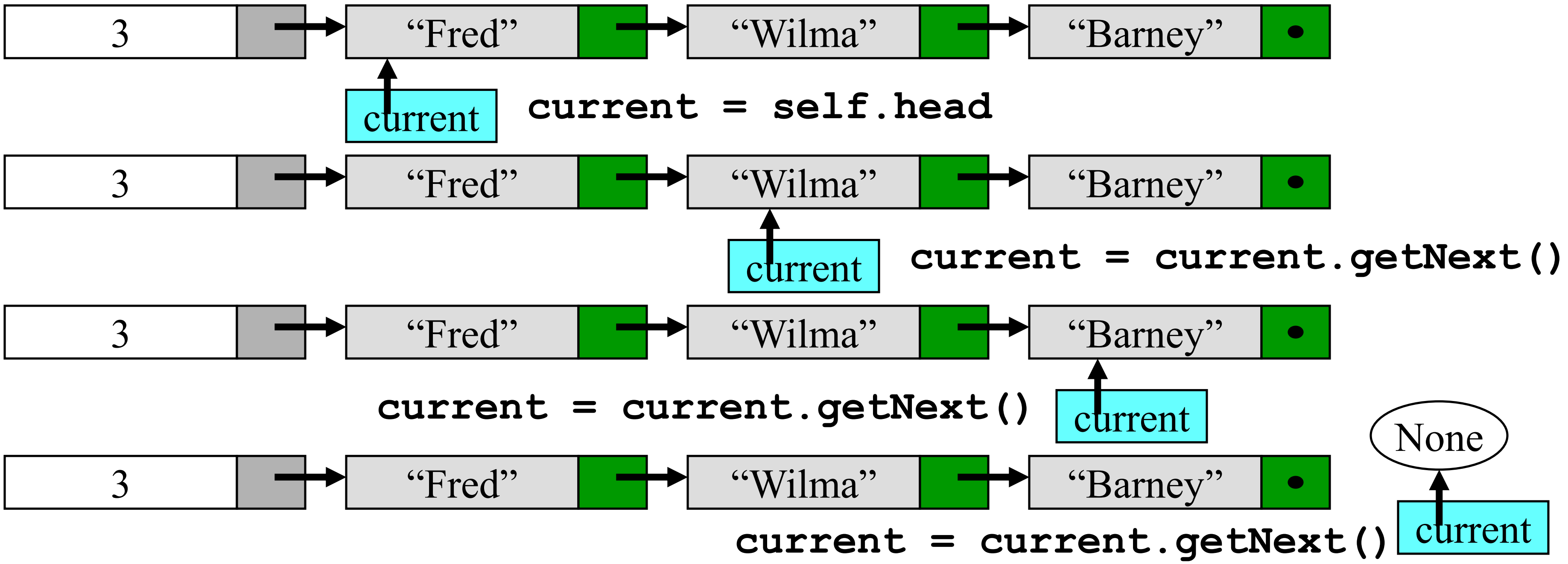


Why Caching the List Size

- The list size could be computed by traversing the list and counting nodes. O(n)
- However, the size is cached as an instance variable so that the size() method can be computed faster. O(1)
- The disadvantage of caching the size as an instance variable is that the instance variable must be updated each time an element is added or removed from the list.

List Traversal

- Many list methods will involve traversal of the list elements from the head to the tail or from the head to a particular element or location.
- We use a cursor (called current) for traversal.



SLinkedList in Python

```
class SLinkedList:
    def __init__(self):
        self.head=None
        self.size=0

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

    def length(self):
        return self.size
```

If we do not cache the size we could traverse the list and count the elements

```
def length(self):
    current = self.head
    count = 0
    while current != None:
        count = count + 1
        current = current.getNext()

    return count
```

Converting to a string

- Before we see the implementations of the other methods in the public interface, we can see how to convert the list to allow it to be printed.
- We simply traverse the list and build a string that contains the elements and put them in between “[“ and “]”

```
def __str__(self):
    s= '['
    i=0
    current=self.head
    while current != None:
        if i>0:
            s = s + ','
        dataObject = current.getData()
        if dataObject != None:
            s = s + "%s" % dataObject
            i = i + 1
        current = current.getNext()
    s = s + ']'
    return s
```

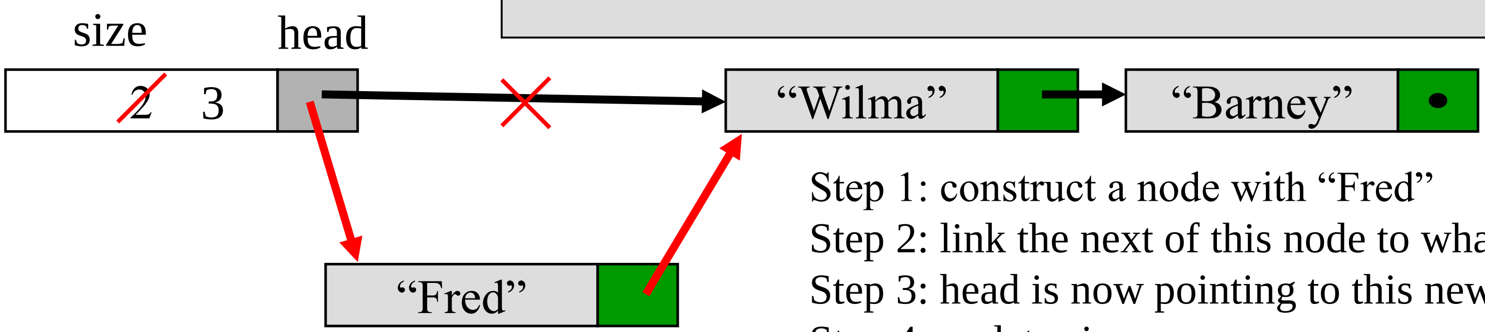
SLinkedList – add(item)

```
def add(self, item):
    # adds an item to list at the beginning

    temp = SLinkedListNode(item,None)
    temp.setNext(self.head)
    self.head = temp
    self.size += 1
```

We could also have done the following:

```
def add(self, item):

    temp = SLinkedListNode(item,self.head)
    self.head = temp
    self.size += 1
```

add("Fred")

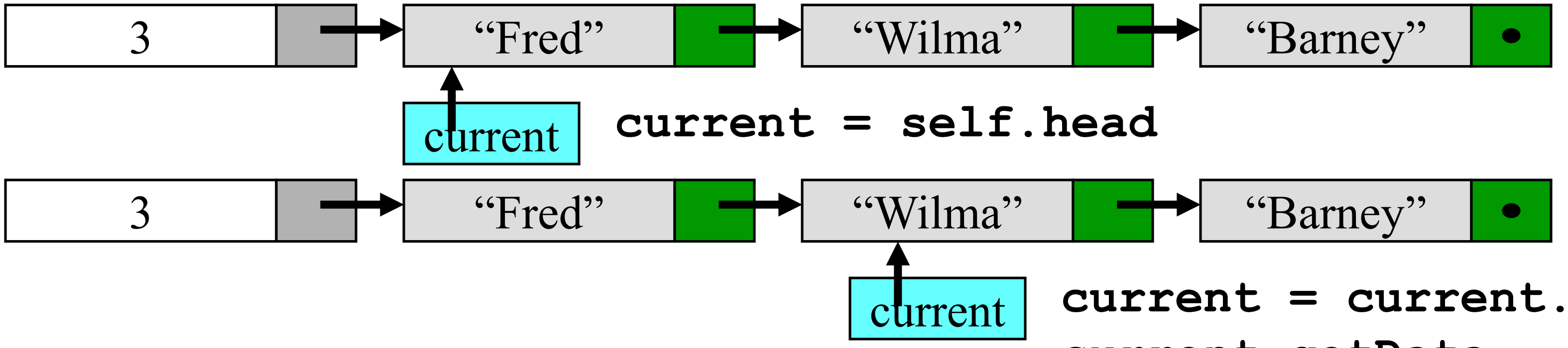


Step 1: construct a node with "Fred"
Step 2: link the next of this node to what head points to
Step 3: head is now pointing to this new node
Step 4: update size

SLinkedList – search(item)

```
def search(self, item):
    current = self.head
    found = False
    while current != None and not found:
        if current.getData() == item:
            found= True
        else:
            current = current.getNext()

    return found
```

search(“Wilma”)



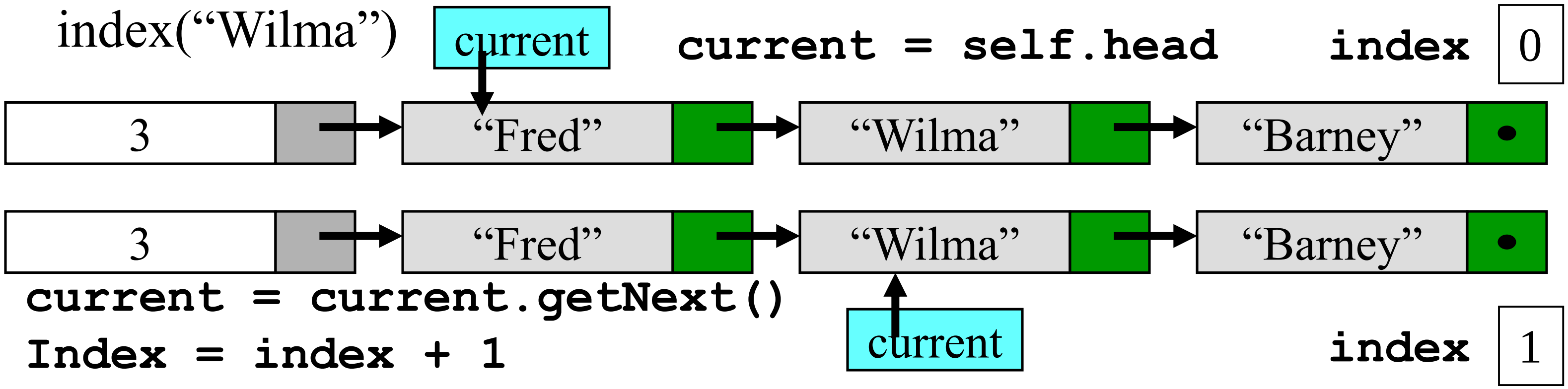
current = self.head

current = current.getNext()

current.getData == “Wilma”

SLinkedList – index(item)

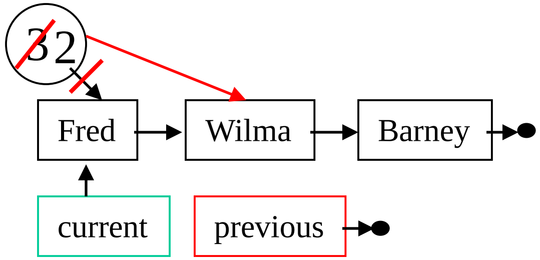
```
def index(self, item):
    # searches for the item and returns its order
    # number(index). Returns -1 if item doesn't exist
    current = self.head
    found = False
    index = 0
    while current != None and not found:
        if current.getData() == item:
            found= True
        else:
            current = current.getNext()
            index = index + 1
    if not found:
        index = -1
    return index
```



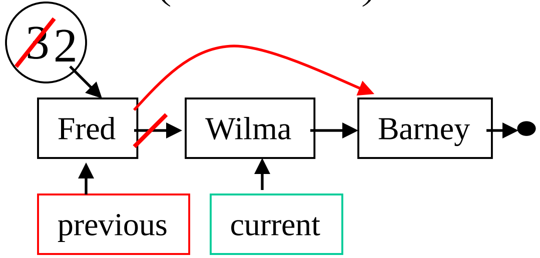
SLinkedList – remove(item)

```
def remove(self, item):
    # searches for the item and removes it
    # the method assumes the item exists
    current = self.head
    previous=None
    found = False
    while not found:
        if current.getData() == item:
            found = True
        else:
            previous = current
            current = current.getNext()
    if previous == None:
        self.head = current.getNext()
    else:
        previous.setNext(current.getNext())
    self.size -= 1
```

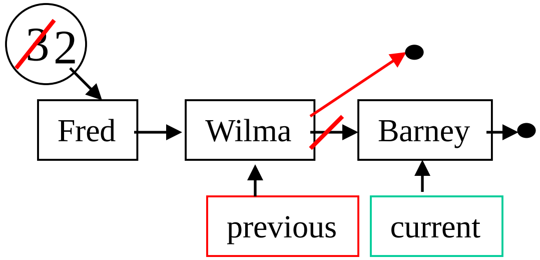
remove(“Fred”)



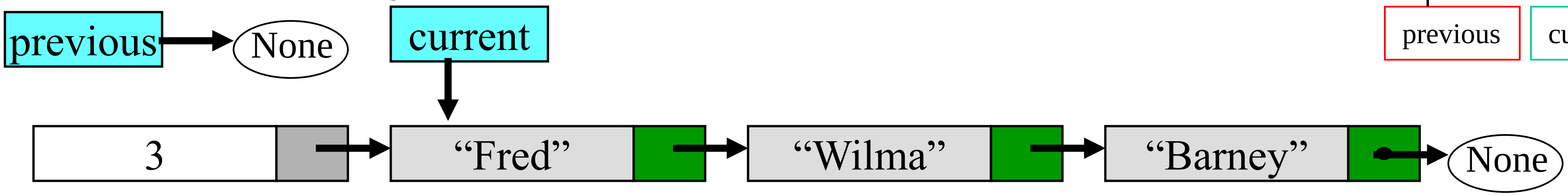
remove(“Wilma”)



remove(“Barney”)



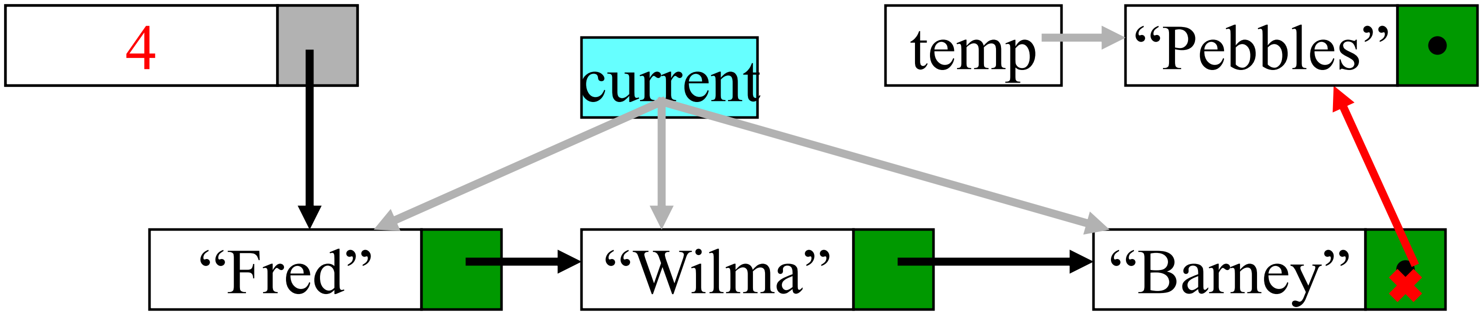
initially



SLinkedList - append(item)

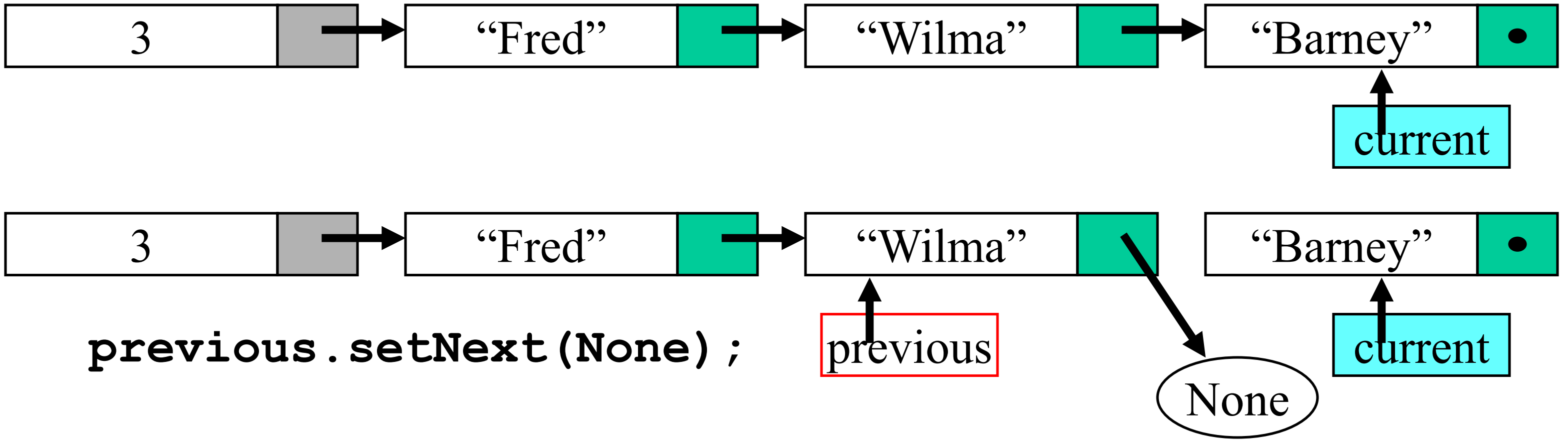
```
def append(self, item):
    # adds the item to the end of the list
    # must traverse the list to the end and add item
    temp = SLinkedListNode(item, None)
    if (self.head == None):
        self.head=temp
    else:
        current = self.head;
        while (current.getNext() != None):
          current = current.getNext()
        current.setNext(temp)
    self.size +=1
```

append(“Pebbles”)



Pop()=Removal From Tail

- We cannot remove from the tail by just traversing to the last node and removing it.
- We need a reference to the second last node so we can set its "next" reference to None.

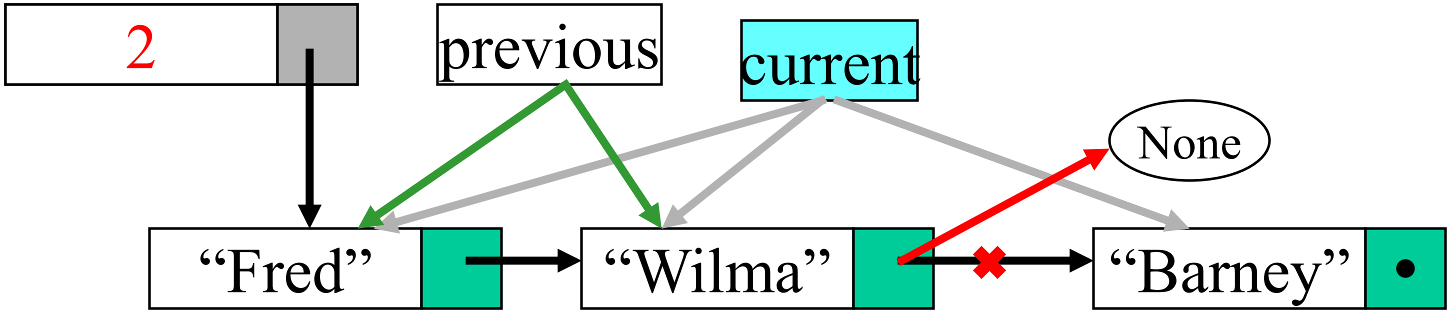


```
previous.setNext(None);
```

- To find the second last node, we need to traverse the list with a second cursor following the first.

SLinkedList - pop()

```
def pop(self):

    current = self.head
    previous = None
    while (current.getNext() != None):
        previous = current
        current = current.getNext()

    if (previous == None):
        self.head = None
    else:
        previous.setNext(None)
    self.size -= 1
    return current.getData()
```



The rest of the methods

- pop(pos) removes and returns the item at a position

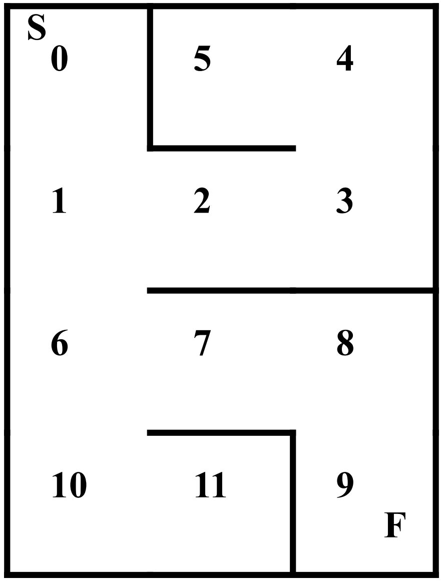
Left as an exercise
There could be other methods such as peek(), clear(), etc.

Linked-List Implementation Advice

- When manipulating references, draw pictures.
- Every public method of an object should leave the object in a consistent state.
- Test the boundaries of your structures and methods.

Linked List for MAZE

- Recall the problem of MAZE traversal from one of the earlier classes.
- We will show here how neighboring positions can be stored using a Linked List.



0 : {1}
1 : {0, 2, 6}
2 : {1, 3}
3 : {2, 4}
4 : {3, 5}
5 : {4}
6 : {1, 7, 10}
7 : {6, 8}
8 : {7, 9}
9 : {8}
10 : {6, 11}
11 : {10}

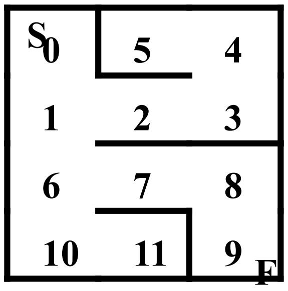
Creating an Adjacency List of Linked Lists

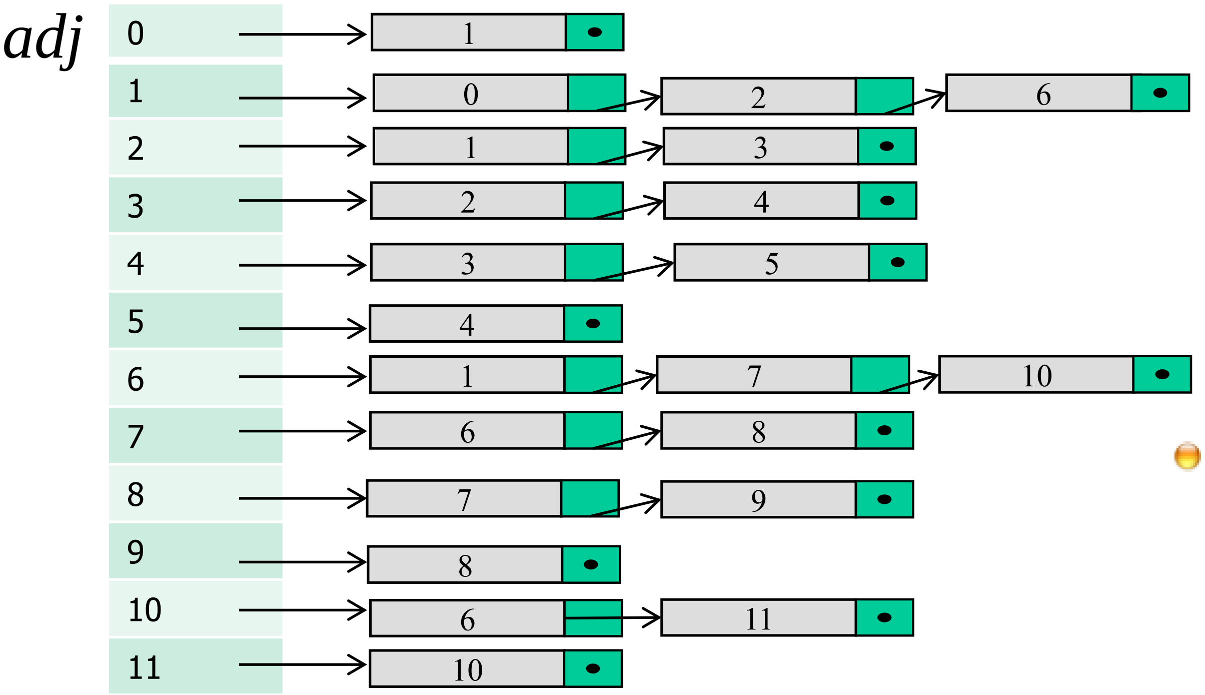
- First create an array of null pointers:

```
adj = []
for i in range(12): #create 0..11 empty lists
    adj.append(None)
```

adj

0	NONE
1	NONE
2	NONE
3	NONE
4	NONE
5	NONE
6	NONE
7	NONE
8	NONE
9	NONE
10	NONE
11	NONE





adj

0 → 1 ●

1 → 0 → 2 → 6 ●

2 → 1 → 3 ●

3 → 2 → 4 ●

4 → 3 → 5 ●

5 → 4 ●

6 → 1 → 7 → 10 ●

7 → 6 → 8 ●

8 → 7 → 9 ●

9 → 8 ●

10 → 6 → 11 ●

11 → 10 ●

- Next create linked lists of legal positions that are adjacent to each position.

Creating an Adjacency List of Linked Lists

- We also need an array “visited” to store whether a state has been visited already

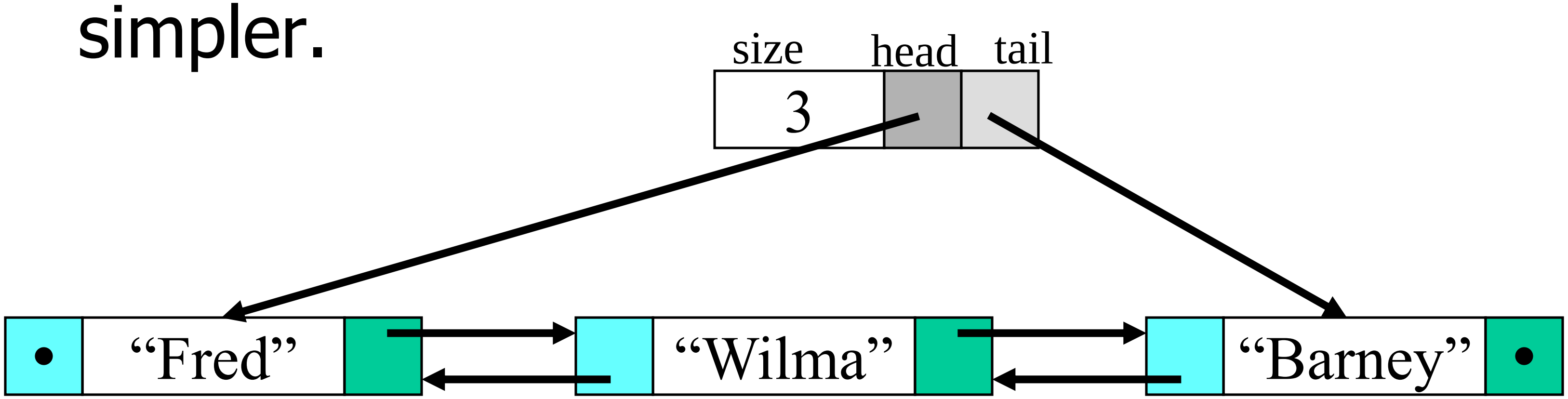
```
visited = []
for i in range(12): #initialize to False, True when visited
    visited.append(False)
```

Solving MAZE problem with Adjacency List & STACK

- With an Adjacency List, the order in which we select the Next Position to Visit depends on the order in which the Positions appear in an adjacency list.
- Recall that with a Stack we go as deep as possible (Depth First) before backing up. The sequence to Depth First Paths we take depends on the order of nodes in the adjacency lists.
- The advantage of the linked list is to insert elements in the beginning of the list in constant time.

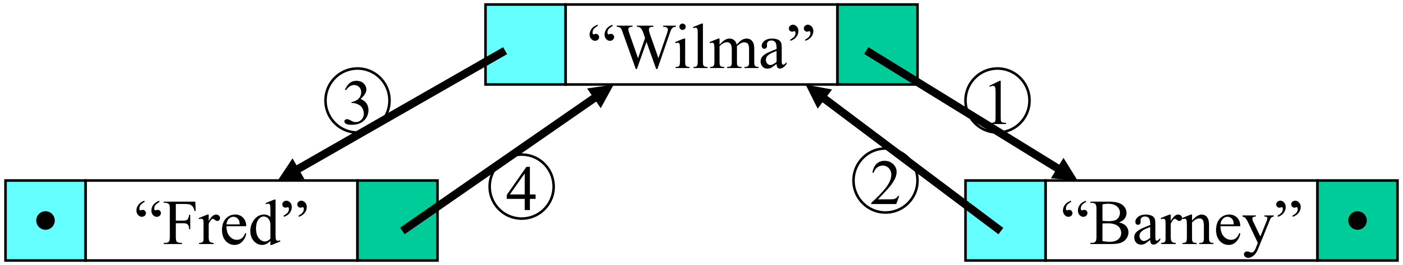
Doubly-Linked List Diagrams

- A doubly-linked list node has two links, one forward and one backward.
- The doubly-linked list has references to its head and tail nodes.
- This symmetry makes the implementation simpler.

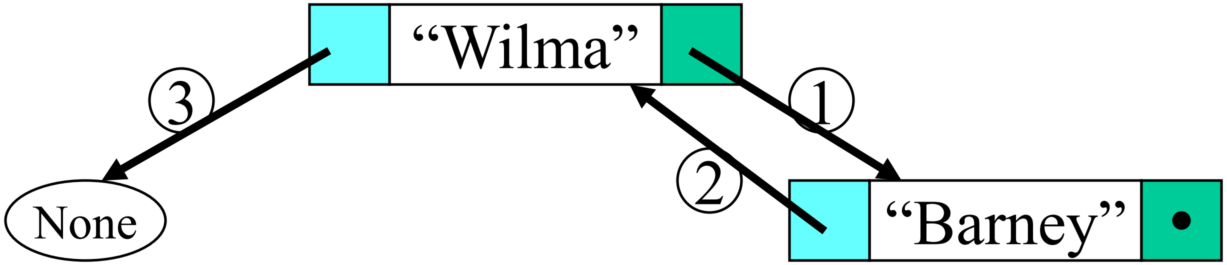


Constructing a Node

- When a DoublyLinkedListElement (node) is constructed, four links may need to be set.

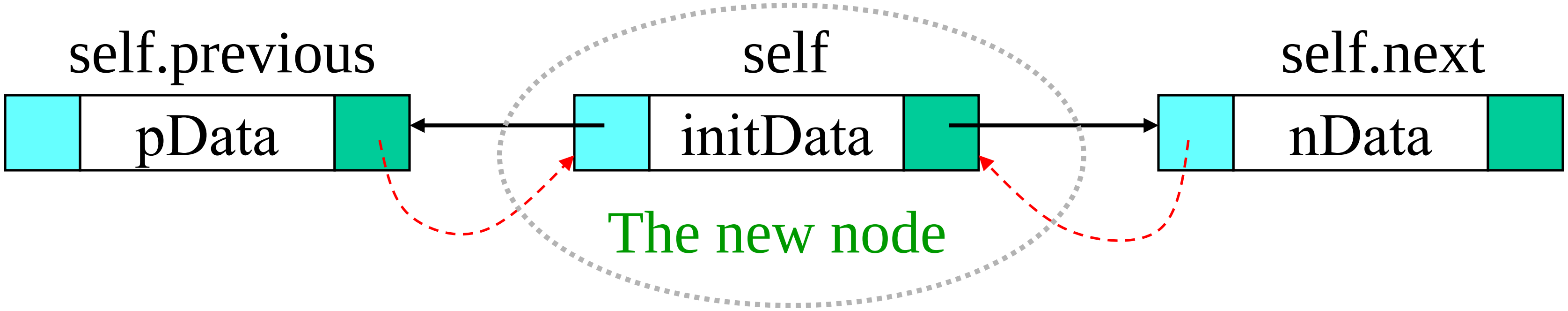


- If one or both of the "neighbouring" nodes is null then fewer links must be set.



DLinkedListNode in Python

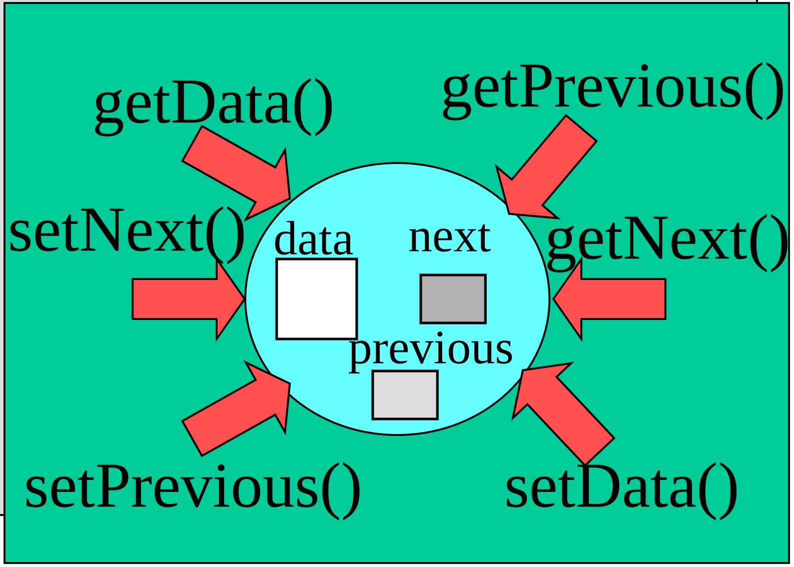
```
class DLinkedListNode:
    def __init__(self, initData, initNext, initPrevious):
    # constructs a new node and initializes it to contain
    # the given object (initData) and links to the given next
    # and previous nodes.

        self.data = initData
        self.next = initNext
        self.previous = initPrevious

        if (initPrevious != None):
            initPrevious.next = self

        if (initNext != None):
            initNext.previous = self
```



DLinkedListNode in Python

```
def getData(self):
    return self.data

def getNext(self):
    return self.next

def getPrevious(self):
    return self.previous


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

def setNext(self, newNext):
    self.next= newNext


def setPrevious(self, newPrevious):
    self.previous= newPrevious
```

Straightforward



DLinkedList in Python

```
class DLinkedList:

    def __init__(self):
        self.head=None
        self.tail=None
        self.size=0





    def isEmpty(self):
        return self.size == 0

    def length(self):
        return self.size
```

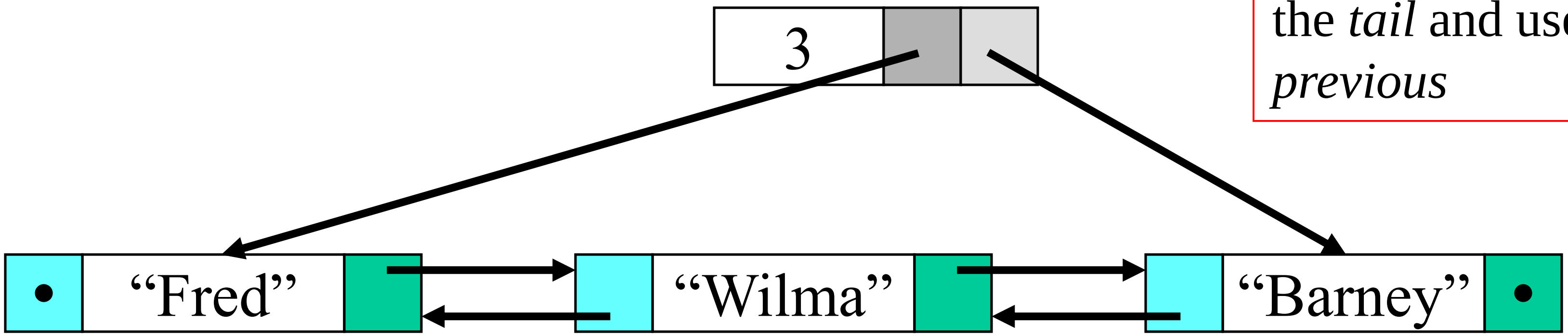
self.head==None

DLinkedList – search(item)

```python
def search(self, item):
    current = self.head
    found = False
    while current != None and not found:
        if current.getData() == item:
            found= True
        else:
            current = current.getNext()

    return found
```

Identical to the search method for SinglyLinkedList

Note that we could also start the traversal from the *tail* and use *previous*

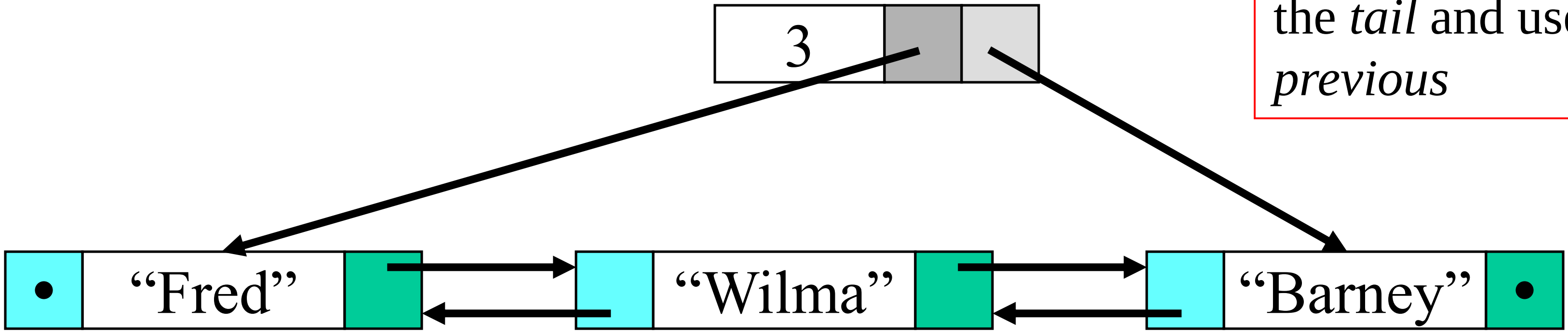


DLinkedList – search(item)

```
def search(self, item):
    current = self.tail
    found = False
    while current != None and not found:
        if current.getData() == item:
            found= True
        else:
            current = current.getPrevious()

    return found
```

Identical to the search method for SinglyLinkedList

Note that we could also start the traversal from the *tail* and use *previous*

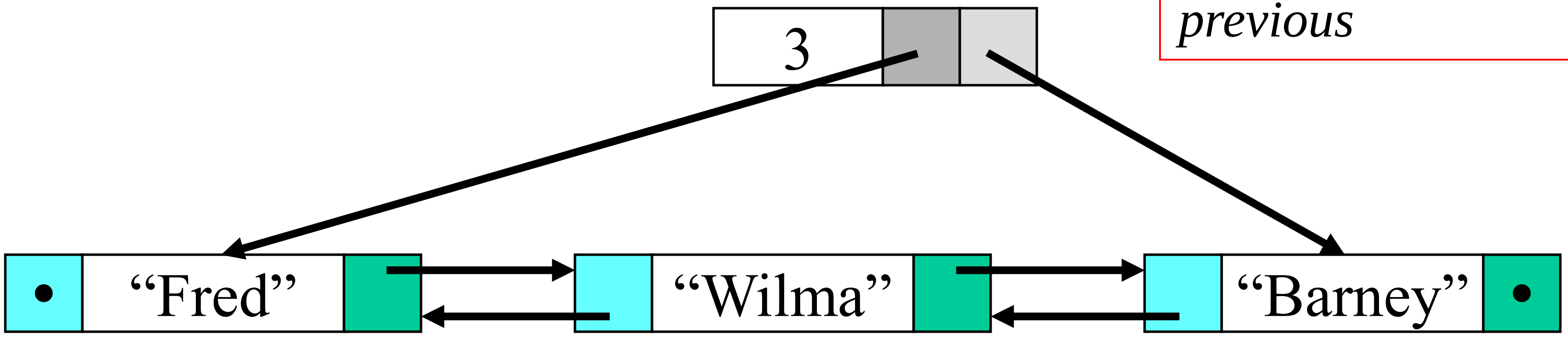


DLinkedList – index(item)

```
def index(self, item):
    current = self.head
    found = False
    index = 0
    while current != None and not found:
        if current.getData() == item:
            found= True
        else:
            current = current.getNext()
            index = index + 1
    if not found:
       index = -1
    return index
```

Identical to the index method for SinglyLinkedList

Note that we could also start the traversal from the *tail* and use *previous*

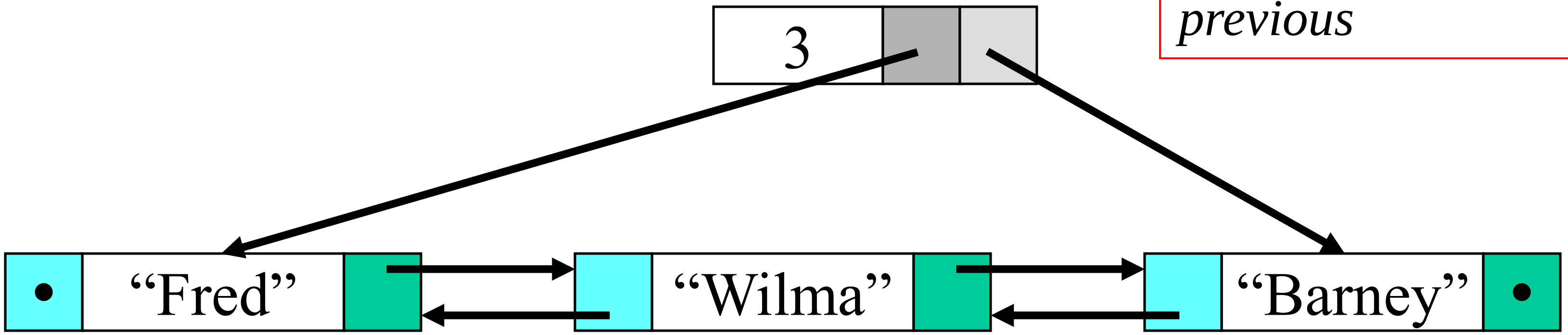


DLinkedList – index(item)

```
def index(self, item):
    current = self.tail
    found = False
    index = self.size-1
    while current != None and not found:
        if current.getData() == item:
            found= True
        else:
            current = current.getPrevious()
            index = index - 1
    if not found:
       index = -1
    return index
```

Identical to the index method for SinglyLinkedList

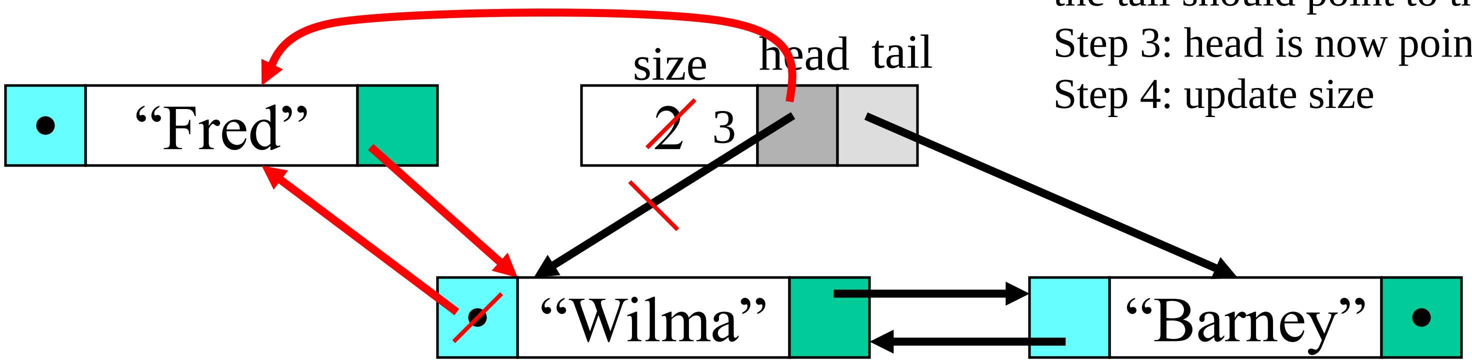
Note that we could also start the traversal from the *tail* and use *previous*



DLinkedList – add(item)

```
def add(self, item):
    # adds an item to list at the beginning

    temp = DLinkedListNode(item, self.head, None)
    if self.head != None:
       self.head.setPrevious(temp)
    else:
       self.tail=temp
    self.head = temp
    self.size += 1
```

add("Fred")

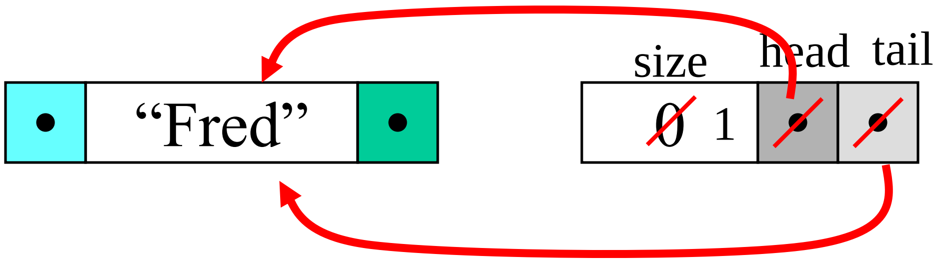


Step 1: construct a new node with "Fred"
Step 2: make the previous of old head to point to new node if the list isn't empty otherwise the tail should point to the new node
Step 3: head is now pointing to this new node
Step 4: update size

DLinkedList – add(item)

```
def add(self, item):
    # adds an item to list at the beginning

    temp = DLinkedListNode(item, self.head, None)
    if self.head != None: #there is a head
       self.head.setPrevious(temp)
    else:                    #there is no head & tail
       self.tail=temp
    self.head = temp
    self.size += 1
```

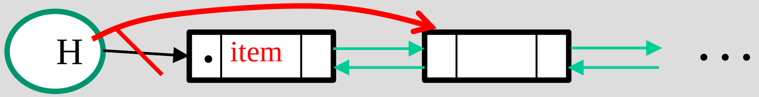
add(“Fred”)



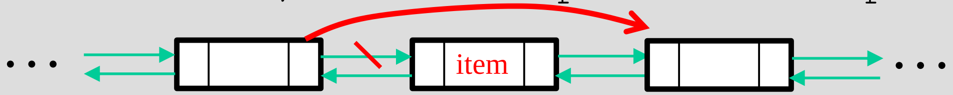
Step 1: construct a new node with “Fred”
Step 2: make the previous of old head to point to new node if the list isn’t empty otherwise the tail should point to the new node
Step 3: head is now pointing to this new node
Step 4: update size

DLinkedList – remove(item)

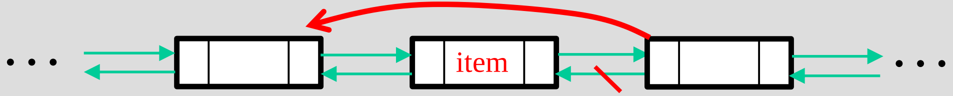
```
def remove(self, item):
    # search for the item and remove it
    # the method assumes the item exists

Traverse the list from head to search for item
If first node, adjust the head to be the next
```



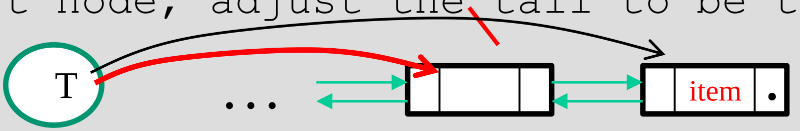
```
If not first node, make the previous to point to next
```



```
If not last node, make the next to point to previous
```

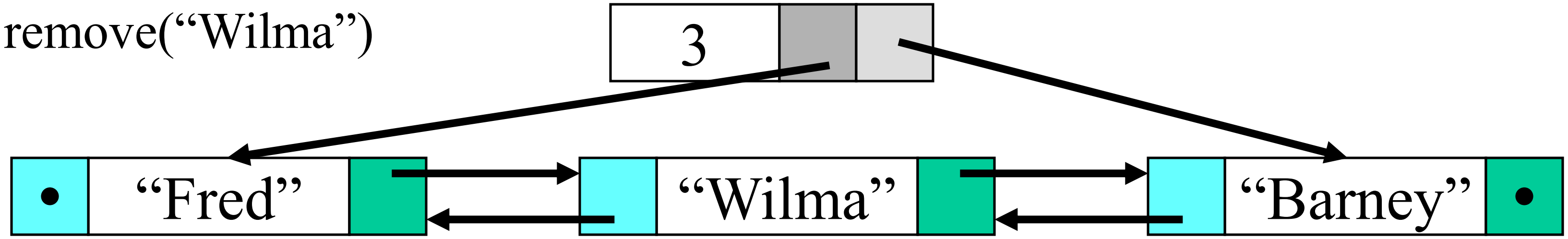


```
If last node, adjust the tail to be the previous
```



```
Reduce size by 1
```

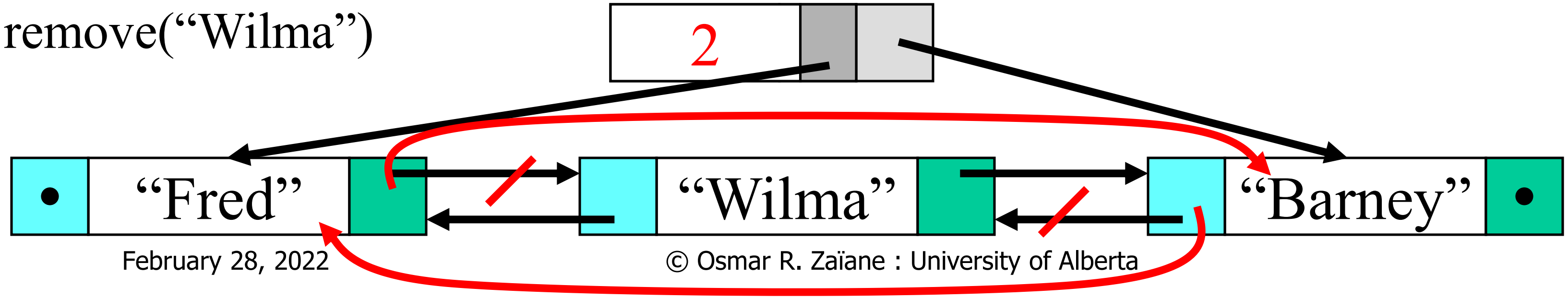
remove(“Wilma”)



DLinkedList – remove(item)

```
def remove(self, item):
    # search for the item and remove it
    # the method assumes the item exists
    current = self.head
    previous=None
    found = False
    while not found:
        if current.getData() == item:
            found = True
        else:
            previous = current
            current = current.getNext()
    if previous == None:
        self.head = current.getNext()
    else:
        previous.setNext(current.getNext())

    if (current.getNext() != None):
        current.getNext().setPrevious(previous)
    else:
        self.tail=previous
    self.size -= 1
```

remove("Wilma")

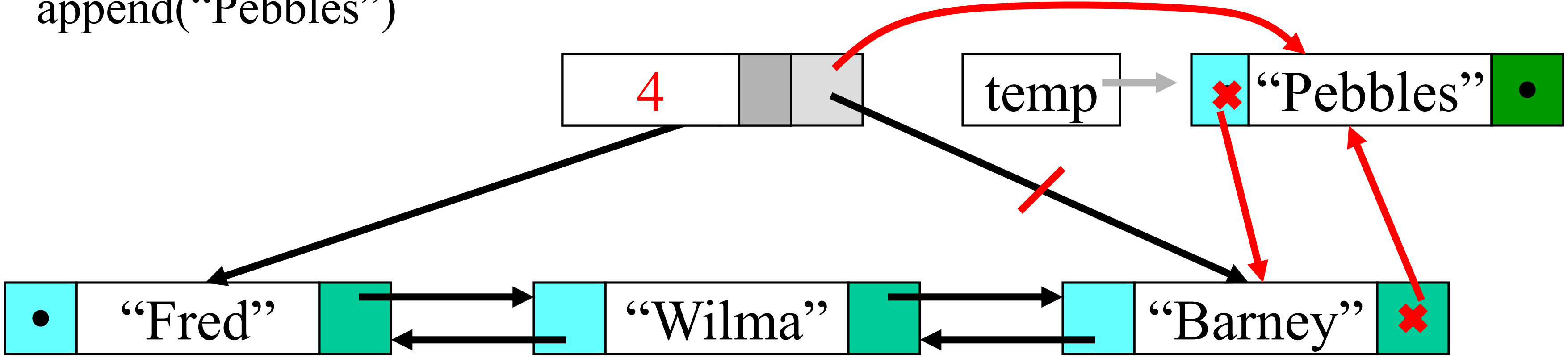


DLinkedList - append(item)

```
def append(self, item):
    # adds the item to the end of the list
    # must traverse the list to the end and add item
    temp = DLinkedListNode(item, None, None)
    if (self.head == None):
        self.head=temp
    else:
        self.tail.setNext(temp)
        temp.setPrevious(self.tail)

    self.tail=temp
    self.size +=1
```

There is no need for traversal

append(“Pebbles”)



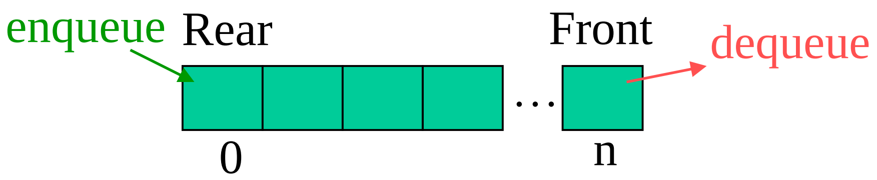
The rest of the methods

- insert(pos,item) adds an item at a given position in list
- pop() removes and returns the last item
- pop(pos) removes and returns the item at a position

Left as an exercise
Try to adapt the methods from SLinkedList Class

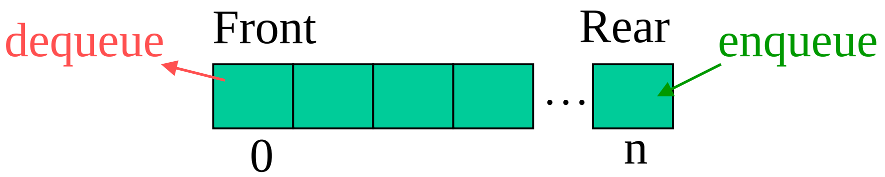
Remember the Queue?

- Rear at position 0.



- dequeue operation is O(1)
- enqueue operation is O(n)

- Front at position 0.

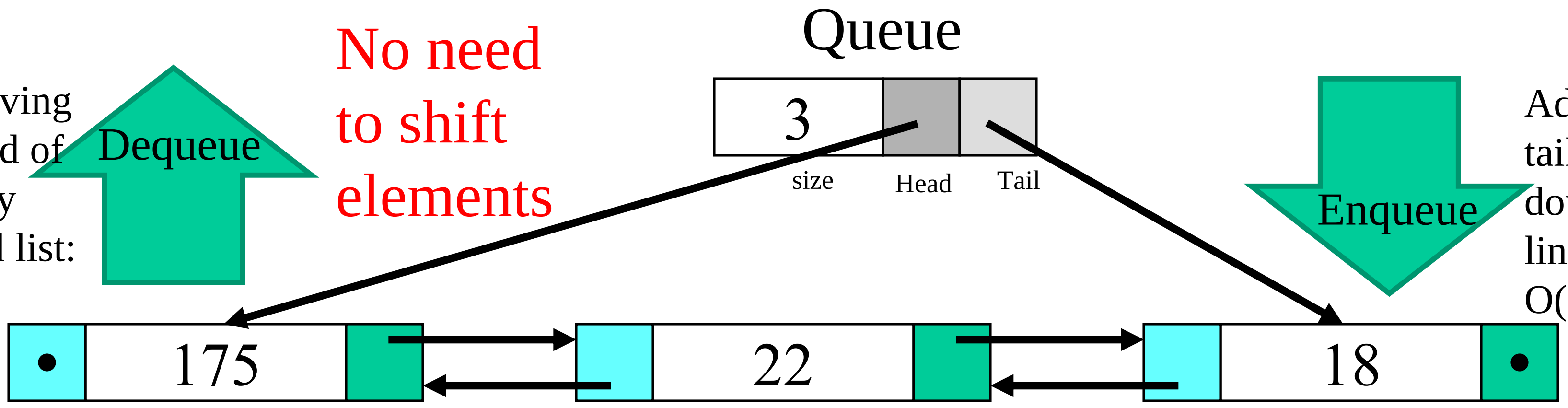


- dequeue operation is O(n)
- enqueue operation is O(1)

Implementing the **Queue** with a **Doubly-Linked-List** allows enqueueing and dequeueing element with O(1)

Removing at head of doubly linked list: O(1)

No need to shift elements



Adding at tail of doubly linked list: O(1)