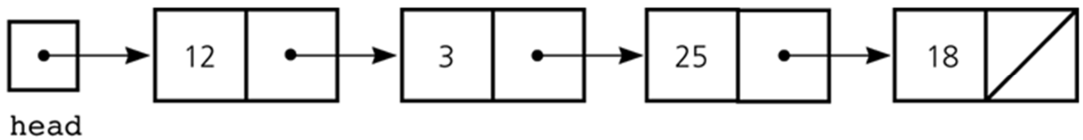
Linked List

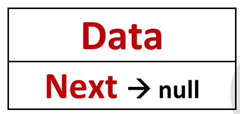
Algorithm - abstract way to perform computation tasks

Data Structure - abstract way to organize information

Linked List:



Node:



Node code:

```
public class Node<T> {
        private T data;
        private Node<T> next;

        public Node(T data) { this.data = data;  }

        public void setData(T data) {  this.data = data;  }
        public T getData() {  return data;  }

        public Node<T> getNext() {  return next;  }
        public void setNext(Node<T> next) {  this.next = next;  }
}
```

Linked List Code:

```
public class LinkedList<T> {
        private Node<T> head;
}
```

Inserting a new node:

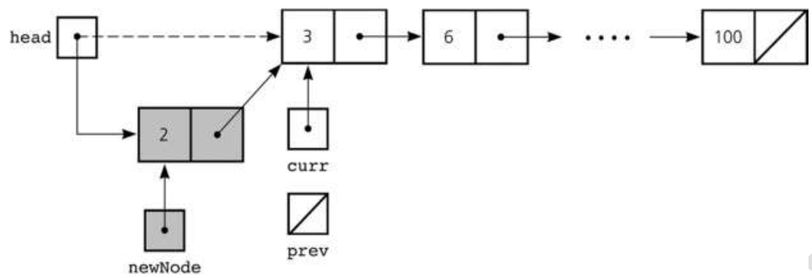
Inserting a Node into a Specified Position of a Linked List:

Three steps to insert a new node into a linked list

- Determine the point of insertion
- Create a new node and store the new data in it
- Connect the new node to the linked list by changing references

Case 1: To insert a node at the beginning of a linked list: (**curr == head**)

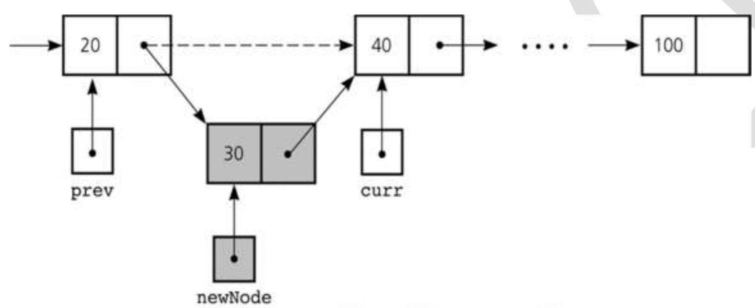
newNode.next = head;
head = newNode;



What's the time complexity of inserting an item to the head?? ➔ **O(1)**

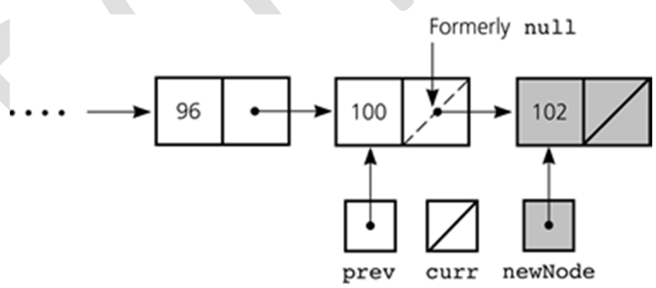
Case 2: To insert a node between two nodes:

newNode.next = curr;
prev.next = newNode;



Case 3: Inserting at the end of a linked list is a special case if **curr** is **null:**

newNode.next = curr;
prev.next = newNode;



Time Complexity ➔ **O(n)**

H.W. ➔ implement insert into a sorted linked list

Determining **curr** and **prev**

Determining the point of insertion or deletion for a sorted linked list of objects

```
for ( prev = null , curr = head;
      (curr != null)  &&  (newValue.compareTo(curr.item) > 0);
```

```
prev = curr , curr = curr.next ) ;   // end for
```

Create a driver class to test linked list classes.
Override the ***toString*** methods first

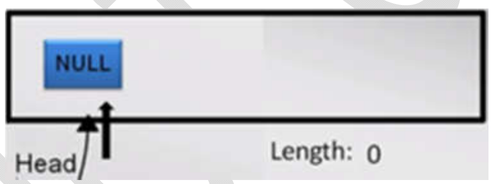
Node toString:

```
@Override
public String toString() {  return data.toString();  }
```

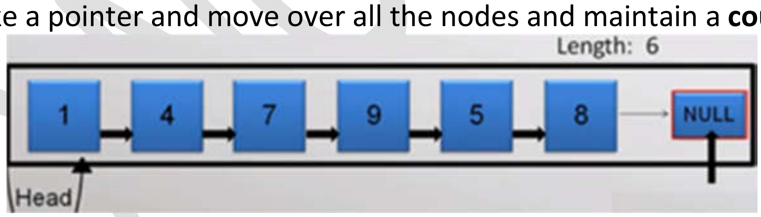
LinkedList toString:

```
@Override
public String toString() {
        String res = "➔";
        Node<T> curr = head;
        while (curr != null) {
                res += curr + "→ ";
                curr = curr.next;
        }
        return res + "NULL";
}
```

Length of Linked List?



Case 1: If it's empty:
Case 2: If not: Make a pointer and move over all the nodes and maintain a **counter**

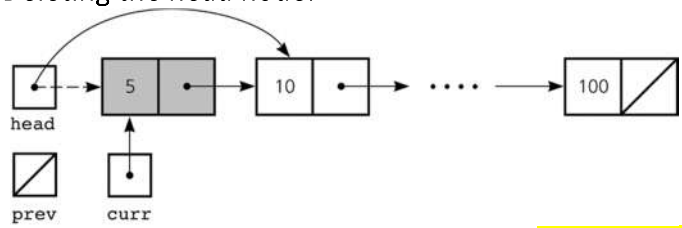


Length code: **Time Complexity ➔ O(n)**

```
public int length() {
        int length = 0;
        Node<T> curr = head;
        while (curr != null) {
                length++;
                curr = curr.next;
        }
        return length;
}
```

Deleting Nodes:

Case 1: Deleting the head node:



Simply move the **head** to the **head.next**: head = head.next;

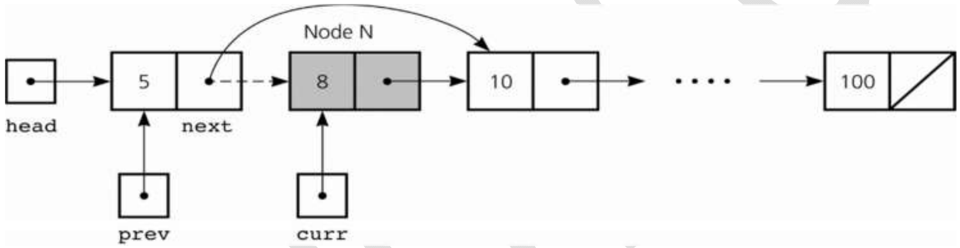
Now first Node has no reference to it ➔ **Garbage**

Time Complexity ➔ **O(1)**

Delete at head code: // **make sure linked list is not empty**

```
public Node<T> deleteAtStart() {
        Node<T> toDel =head;
        head = head.next;
        return toDel;
}
```

Case 2: Delete node **N** which **curr** references:



Set **next** in the node that precedes **N** to reference the node that follows **N**

```
prev.next = curr.next;  // prev.next = prev.next.next;
```

Searching for an Item in a Linked List:

Time Complexity: linear growth ➔ **O(n)**

Find code:

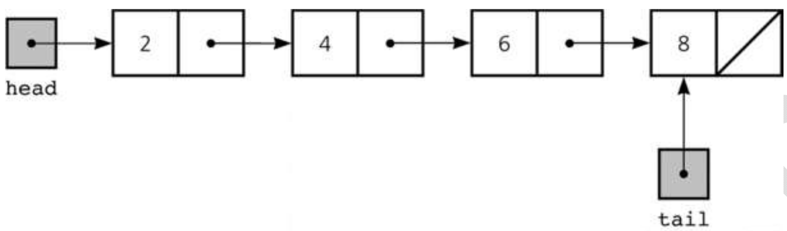
```
public Node<T> find(T data) {
        Node<T> curr =  head;
        while (curr != null) {
                if (curr.getData() == data)    //  if (curr.getData().equals(data))
                        return curr;
                curr = curr.next;
        }
        return null;
}
```

Variations of the Linked List:

1- Tail References (Doubly Ended Linked List)

- Remembers where the end of the linked list is.
- Therefore, we can add and delete at both ends.
- To add a node to the end of a linked list

  tail.next = new Node(request, null);



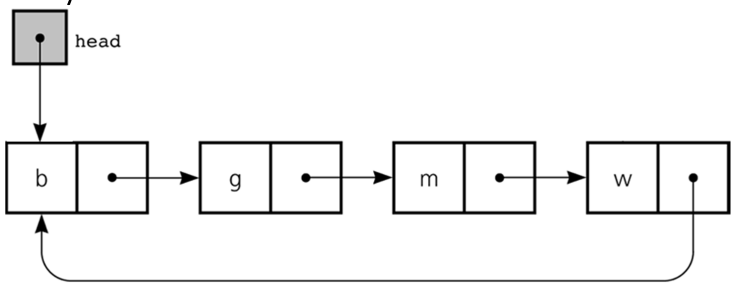

```
public class DoubleEndedList<T> extends LinkedList<T> {
        private Node<T> tail;
        public Node<T> getTail() {        return tail;   }

        public void addAtEnd(T data) {
                Node<T> newNode = new Node<T>(data);
                if (head == null) {  // empty
                        head = newNode;
                        tail = newNode;
                }
                        else {
                        tail.setNext(newNode);
                        tail = newNode;
                }
        }
}
```

Make sure to override addAtStart to set the tail pointer correctly:

```
@Override
public void addAtStart(T data) {
    Node<T> newNode = new Node<T>(data);
    if (head == null) {  // empty
        head = newNode;
        tail = newNode;
    }
    else{
        newNode.setNext(head);
        head = newNode;
    }
}
```

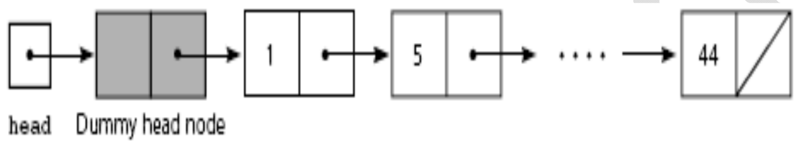
2- Circular Linked List

– Last node references the first node
– Every node has a successor



3- Dummy Head Nodes

– Always present, even when the linked list is empty
– Insertion and deletion algorithms initialize **prev** to reference the dummy head node, rather than **null**



Processing Linked Lists Recursively:

- **Traversal**
  – Recursive strategy to display a list
  Write the first node of the list
  Write the list minus its first node

```
public static void traversList(Node curr) {
  if(curr == null)
    System.out.println("NULL");
  else {
     System.out.print("[" + curr + "]-->");
     traversList(curr.next);
  }
}
```

  – Recursive strategies to display a list backward
    - writeListBackward strategy
      Write the last node of the list
      Write the list minus its last node backward

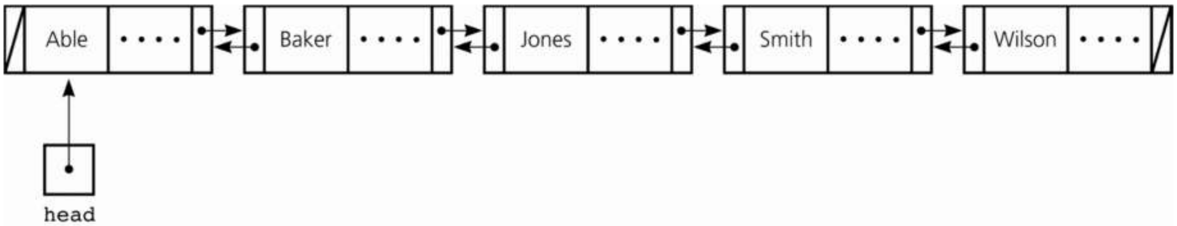
```
public static void traversListBackward(Node curr) {
  if(curr == null)
    System.out.print("NULL");
  else {
    traversListBackward(curr.next);
    System.out.print("<--[" + curr + "]");
  }
}
```

Doubly Linked List

Node:

Date
Next → null
null ← Prev

Doubly Linked List: Each node references both its predecessor and its successor:



Doubly Node Code:

```
public class DNode <T extends Comparable<T>>{
    T data;
    DNode next;
    DNode prev;

    public DNode(T data) { this.data = data; }
    public T getData() { return data;  }
    public DNode getNext () { return next; }
    public DNode getPrev () { return prev; }

    public void setNext(DNode next) {   this.next = next; }
    public void setPrev(DNode prev) {   this.prev = prev; }
    public String toString() { return this.data.toString();  }
}
```

Doubly Linked List code:

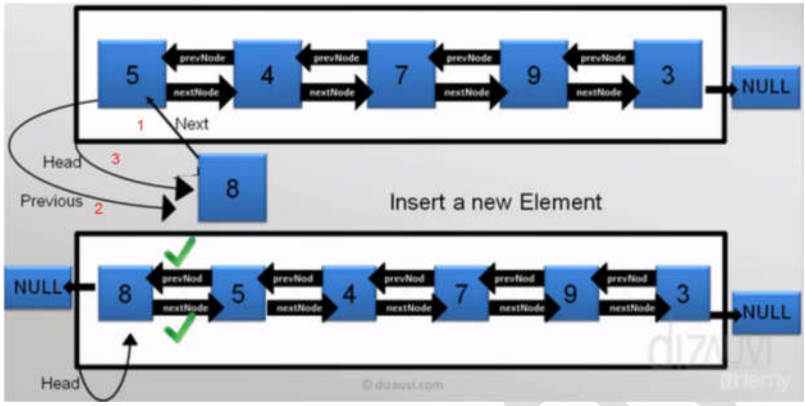
```
public class DLinkedList <T extends Comparable<T>>{
    DNode head;
}
```

Override toString method code:

```
public String toString() {
    String res = "Head-->";
    DNode<T> curr = this.head;
    while (curr != null) {
        res += "["+curr + "]";
        curr = curr.getNext();
        if(curr!=null)
            res +="<=>";
    }
    return res + "-->NULL";
}
```

Insert a new node (not sorted)

Case 1: Insert at head:




```
public void insertAtHead(T data) {
   DNode<T> newNode = new DNode(data);
   if(head==null) // empty linkedlist
      head = newNode;
   else {
      newNode.setNext(this.head);
      head.setPrev(newNode);
      head = newNode;
   }
}
```

Case 2: Insert at end:

Student Activity: insert at last

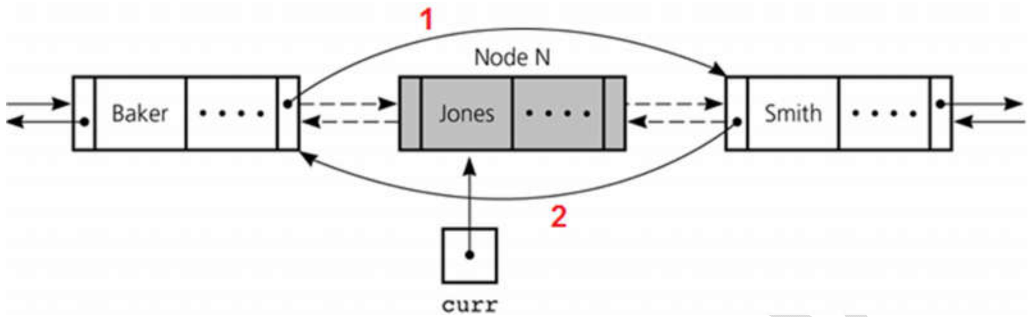
```
public void insertAtEnd(T data) {
   DNode<T> newNode = new DNode(data);
   if (head == null) // empty linkedlist
      head = newNode;
   else { // find last node
      DNode<T> last = head;
      while(last.getNext() != null)
         last = last.getNext();
      last.setNext(newNode);
      newNode.setPrev(last);
   }
}
```

Length of a doubly linked list code:

```
public int length() {
   int length = 0;
   DNode<T> curr = this.head;
   while (curr != null) {
      length++;
      curr = curr.getNext();
   }
   return length;
}
```

Delete a node:

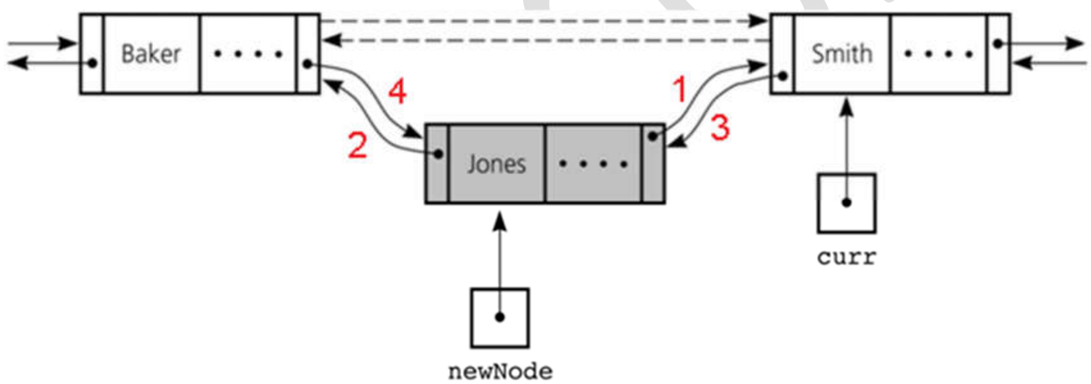
- To delete the node that **curr** pointer references



curr.prev.next = curr.next;
curr.next.prev = curr.prev;

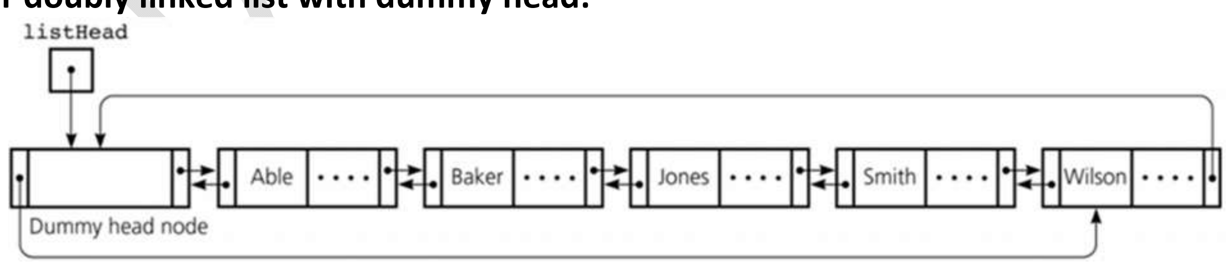
Insert a new Node (Sorted):

- To insert a new node that **newNode** references before the node referenced by **curr**



newNode.next = curr;	// 1
newNode.prev = curr.prev;	// 2
curr.prev = newNode;	// 3
newNode.prev.next = newNode;	// 4

Circular doubly linked list with dummy head:

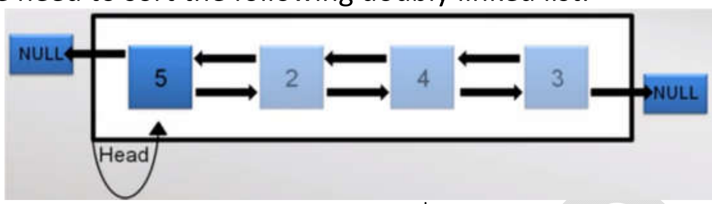


- Preceding reference of the dummy head node references the last node.
- next reference of the last node references the dummy head node.
- **Eliminates special cases for insertions and deletions.**

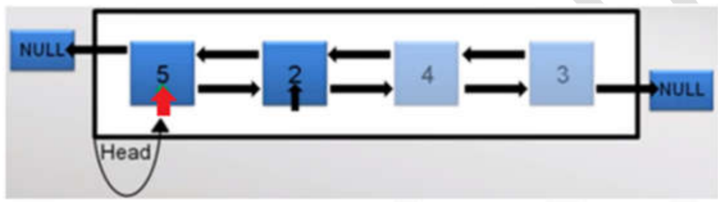
Case Study: Insertion Sort using doubly linked list (Using NO extra space):

Review insertion sort logic and point to problem of insertion and time needed to shift the items
Worst case if the array is reverse sorted

Example: assume we need to sort the following doubly linked list:



Assumption: 1st node is sorted. We start from the 2nd element:



Here:

- The **black** pointer points to the **current** node to be sorted.
- The **red** pointer points to previous node of **current** node to be sorted.
- The **green** pointer points to next node of **current** node to be sorted.

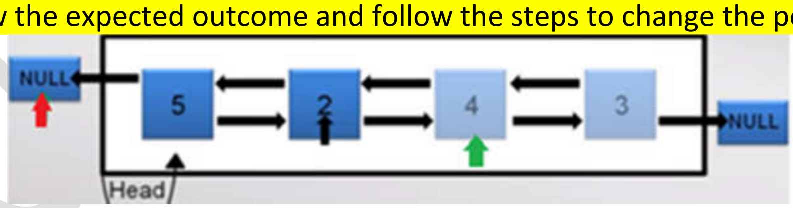
Step 1: The **red** pointer keeps move backward until it reaches a node which has a value **smaller** than the **current** node **or** reach **NULL**.

Step 2: the **current** item will be inserted after **red** pointer as follow:

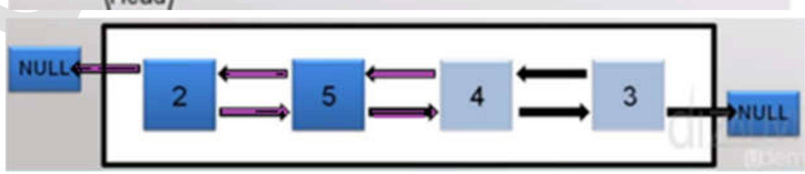
Make sure you maintain references correctly.

To do so draw the expected outcome and follow the steps to change the pointers:

Initial state:



Final state:

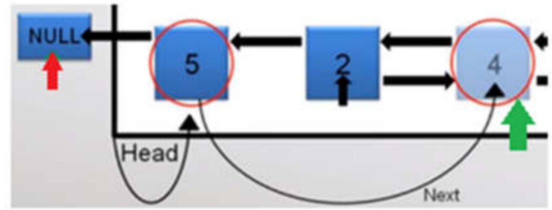


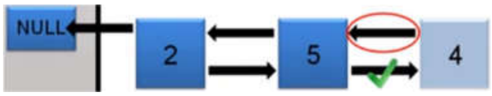
Case 1: insert to head

Step 2.0: make new green pointer = black.next

Step 2.1:

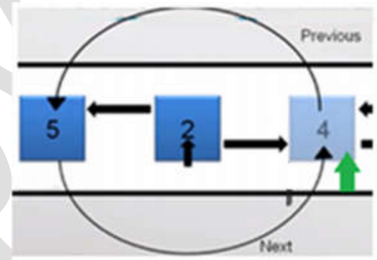
➔ **black.prev.next = green**

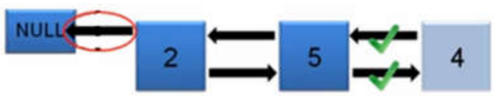


Step 2.2: 

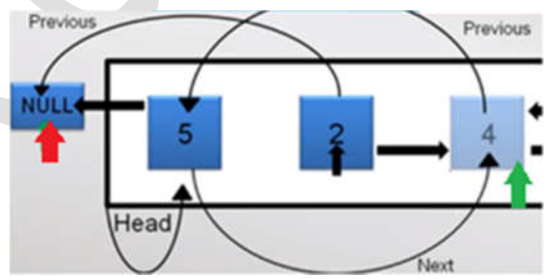
➔

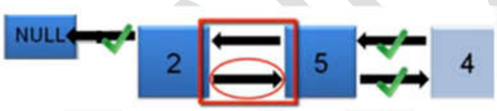
if (green != null) **green**.prev = black.prev



Step 2.3: 

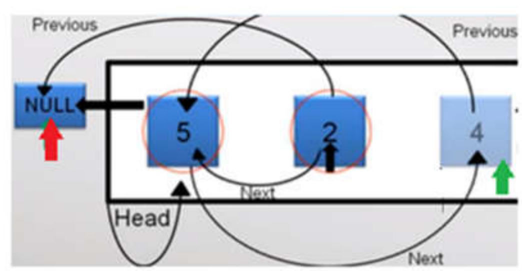
➔ black.prev = **red**

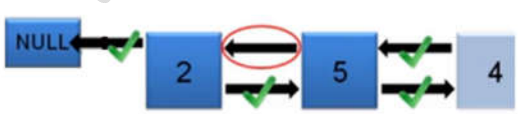


Step 2.4: 

➔

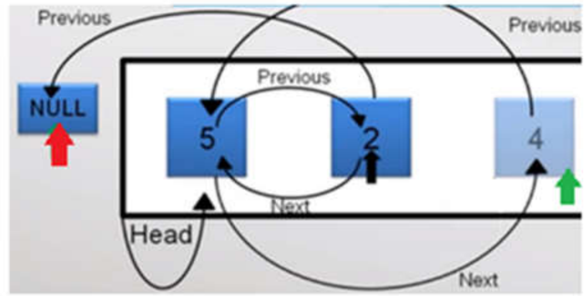
if(red==null) black.next = black.next.prev
else black.next = red.next



Step 2.5: 

➔

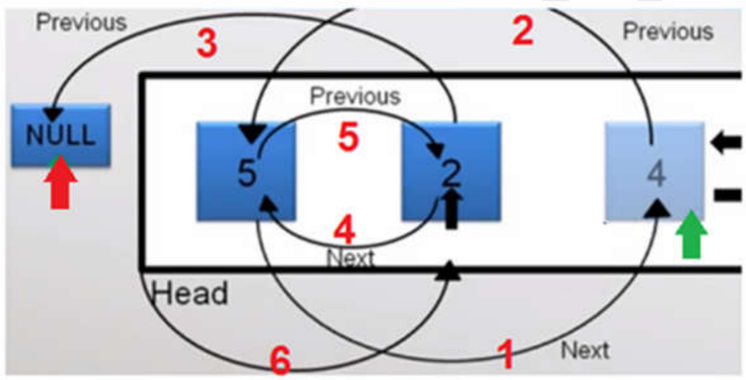
If (red == null) black.next.prev = black
else red.next.prev = black



Step 2.6:

if (red == NULL) head = black

else red.next = black;

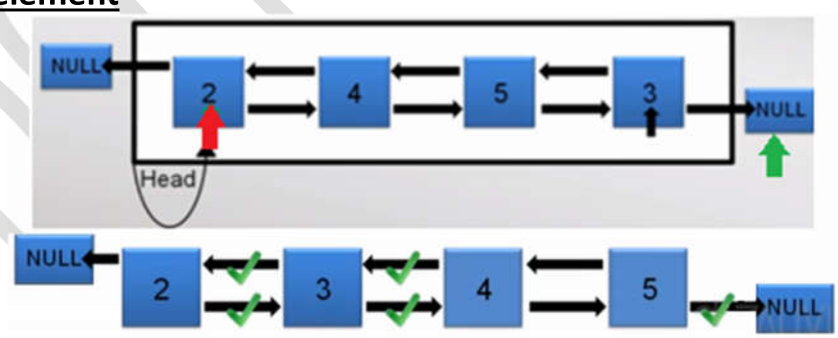


Step 2.7: black = green

Case 2: insert 4 in the middle

Practice yourself

Case 3: insert last element



Insertion Sort Code:

```
// Insertion Sort of a Doubly Linked List
public void sort() {
  DNode black = head.next;
  while (black != null) {
    DNode red = black.prev;
    while (red != null && (red.data.compareTo(black.data) > 0 ))  // step 1.0
      red = red.prev;

    DNode green = black.next;            // step 2.0
    if (red != null || (head != black)) {
      black.prev.next = green;           // step 2.1
      if (green!= null) {
        green.prev = black.prev;         // step 2.2
      }
      black.prev = red;                  // step 2.3
    }
    if (red == null) {   // set the black as head
      if (head != black) {
        black.next = head;               // step 2.4
        black.next.prev = black;         // step 2.5
        head = black;                    // step 2.6
      }
    } else {   // red is not null
      black.next = red.next;             // step 2.4
      red.next.prev = black;             // step 2.5
      red.next = black;                  // step 2.6
    }
    black = green;  // step 2.7
  }
}
```