Implementing Lists, Stacks, Queues, and Priority Queues

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Objectives

- To **design common features of lists in an interface and** provide skeleton implementation in **an abstract class** for Collections.
- To design and implement a **dynamic list using an array**.
- To design and implement a **dynamic list using a linked structure**.
- To **design and implement a stack class** using an array list **and a queue class using a linked list**.
- To **design and implement a priority queue using a heap**.

Lists

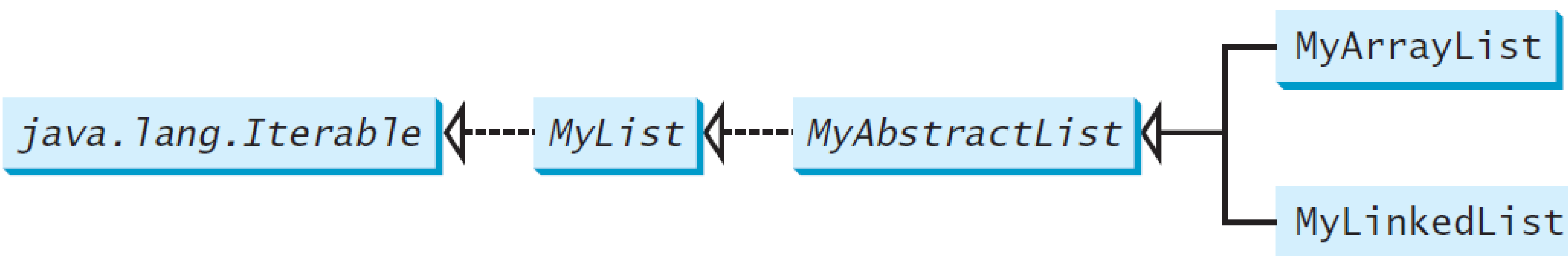
- A ***list*** is a popular data structure to store data in **sequential** order
  - For example, a list of students, a list of available rooms, a list of cities, and a list of books, etc. can be stored using lists
  - The common operations on a list are usually the following:
    - ***Retrieve*** an element from the list
    - ***Insert*** a new element to the list
    - ***Delete*** an element from the list
    - Find ***how many*** elements are in the list
    - Find ***if an element is in the list***
    - Find if the list is ***empty***

Two Ways to Implement Lists

- There are two ways to implement a list:
  - ***Using arrays*** to store the elements: the array is dynamically created
    - If the capacity of the array is exceeded, create a new larger array and copy all the elements from the current array to the new array
  - ***Using linked list*** consisting of nodes
    - Each node is dynamically created to hold an ***element***
    - All the nodes are linked together to form a list
- For convenience, let's name these two classes: **`MyArrayList`** and **`MyLinkedList`**

Design of **`ArrayList`** and **`LinkedList`**

- The two classes have common operations, but different data fields
  - The common operations can be generalized in an interface or an abstract class
  - A good strategy is to combine the virtues of interfaces and abstract classes by providing both interface and abstract class in the design so the user can use either the interface or the abstract class whichever is convenient -> Such an abstract class is known as a ***convenience class***



`MyList` Interface and `MyAbstractList` Class

«interface» *java.lang.Iterable<E>*	
+iterator(): Iterator<E>	Returns an iterator for the elements in this collection.

«interface» *MyList<E>*	
+add(e: E): void	Appends a new element at the end of this list.
+add(index: int, e: E): void	Inserts a new element at the specified index in this list.
+clear(): void	Removes all the elements from this list.
+contains(e: E): boolean	Returns true if this list contains the specified element.
+get(index: int): E	Returns the element from this list at the specified index.
+indexOf(e: E): int	Returns the index of the first matching element in this list.
+isEmpty(): boolean	Returns true if this list does not contain any elements.
+lastIndexOf(e: E): int	Returns the index of the last matching element in this list.
+remove(e: E): boolean	Removes the element from this list.
+size(): int	Returns the number of elements in this list.
+remove(index: int): E	Removes the element at the specified index and returns the removed element.
+set(index: int, e: E): E	Sets the element at the specified index and returns the element being replaced.

MyAbstractList<E>	
#size: int	The size of the list.
#MyAbstractList()	Creates a default list.
#MyAbstractList(objects: E[])	Creates a list from an array of objects.
+add(e: E): void	Implements the `add` method.
+isEmpty(): boolean	Implements the `isEmpty` method.
+size(): int	Implements the `size` method.
+remove(e: E): boolean	Implements the `remove` method.

```java
public interface MyList<E> extends Iterable<E> {
  /** Add a new element at the end of this list */
  public void add(E e);

  /** Add a new element at the specified index in this list */
  public void add(int index, E e);

  /** Clear the list */
  public void clear();

  /** Return true if this list contains the element */
  public boolean contains(E e);

  /** Return the element from this list at the specified index */
  public E get(int index);

  /** Return the index of the first matching element in this list.
   *  Return -1 if no match. */
  public int indexOf(E e);

  /** Return true if this list contains no elements */
  public boolean isEmpty();

  /** Return the index of the last matching element in this list
   *  Return -1 if no match. */
  public int lastIndexOf(E e);
```

```
  /** Remove the first occurrence of the element o from this list.
   *  Shift any subsequent elements to the left.
   *  Return true if the element is removed. */
  public boolean remove(E e);

  /** Remove the element at the specified position in this list
   *  Shift any subsequent elements to the left.
   *  Return the element that was removed from the list. */
  public E remove(int index);

  /** Replace the element at the specified position in this list
   *  with the specified element and returns the new set. */
  public E set(int index, E e);

  /** Return the number of elements in this list */
  public int size();

}
```

```java
public abstract class MyAbstractList<E> implements MyList<E> {
  protected int size = 0; // The size of the list

  /** Create a default list */
  protected MyAbstractList() {
  }

  /** Create a list from an array of objects */
  protected MyAbstractList(E[] objects) {
    for (int i = 0; i < objects.length; i++)
      add(objects[i]);
  }

  /** Add a new element at the end of this list */
  public void add(E e) {
    add(size, e);
  }

  /** Return true if this list contains no elements */
  public boolean isEmpty() {
    return size == 0;
  }

  /** Return the number of elements in this list */
  public int size() {
    return size;
  }
```

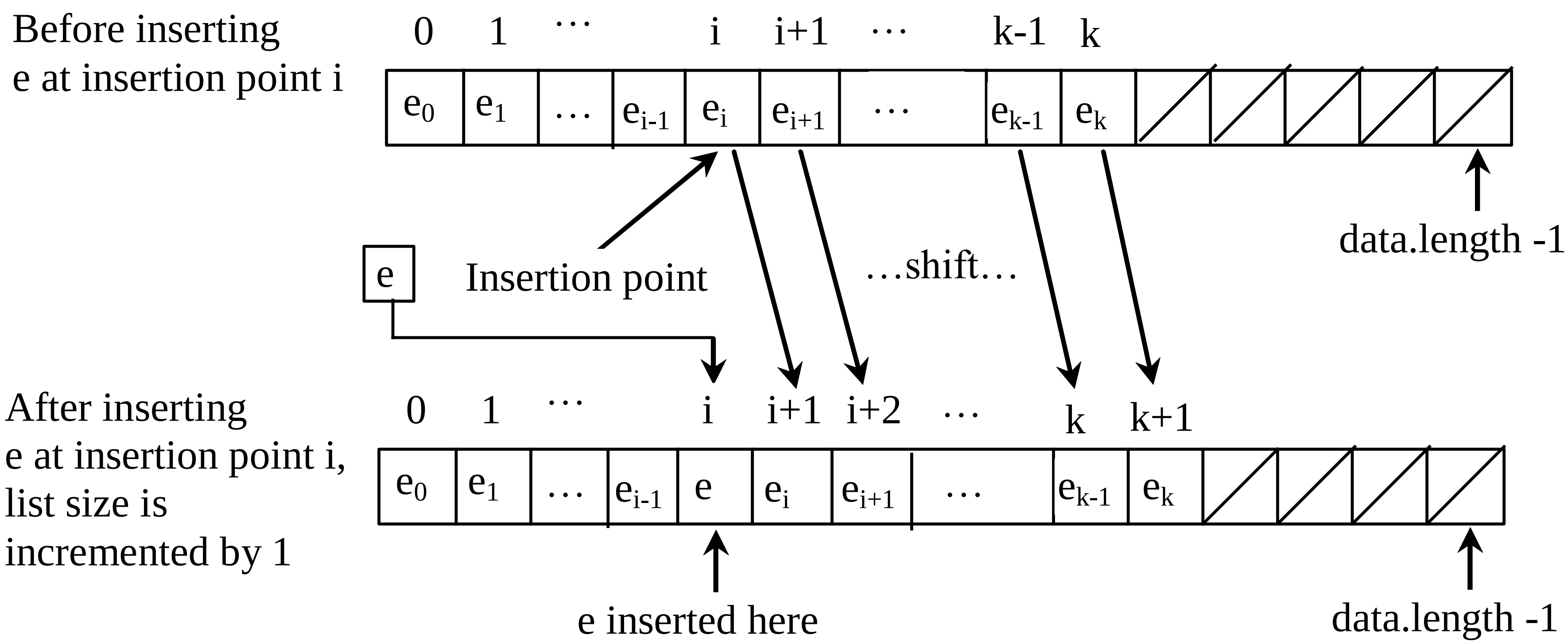
```java
  /** Remove the first occurrence of the element o from this list.
   *  Shift any subsequent elements to the left.
   *  Return true if the element is removed. */
  public boolean remove(E e) {
    int i = indexOf(e);
    if (i >= 0) {
      remove(i);
      return true;
    } else
      return false;
  }

}
```

Array Lists

- Array is a fixed-size data structure:
  - Once an array is created, its size cannot be changed
- However, we can still use array to implement dynamic data structures by creating a new larger array to replace the current array if the current array cannot hold new elements in the list
- Initially, an array, say data of **`Object[]`** type, is created with a default size
  - When inserting a new element into the array, first ensure there is enough room in the array
    - If not, create a new array with the size as twice as the current one, copy the elements from the current array to the new array and the new array now becomes the current array

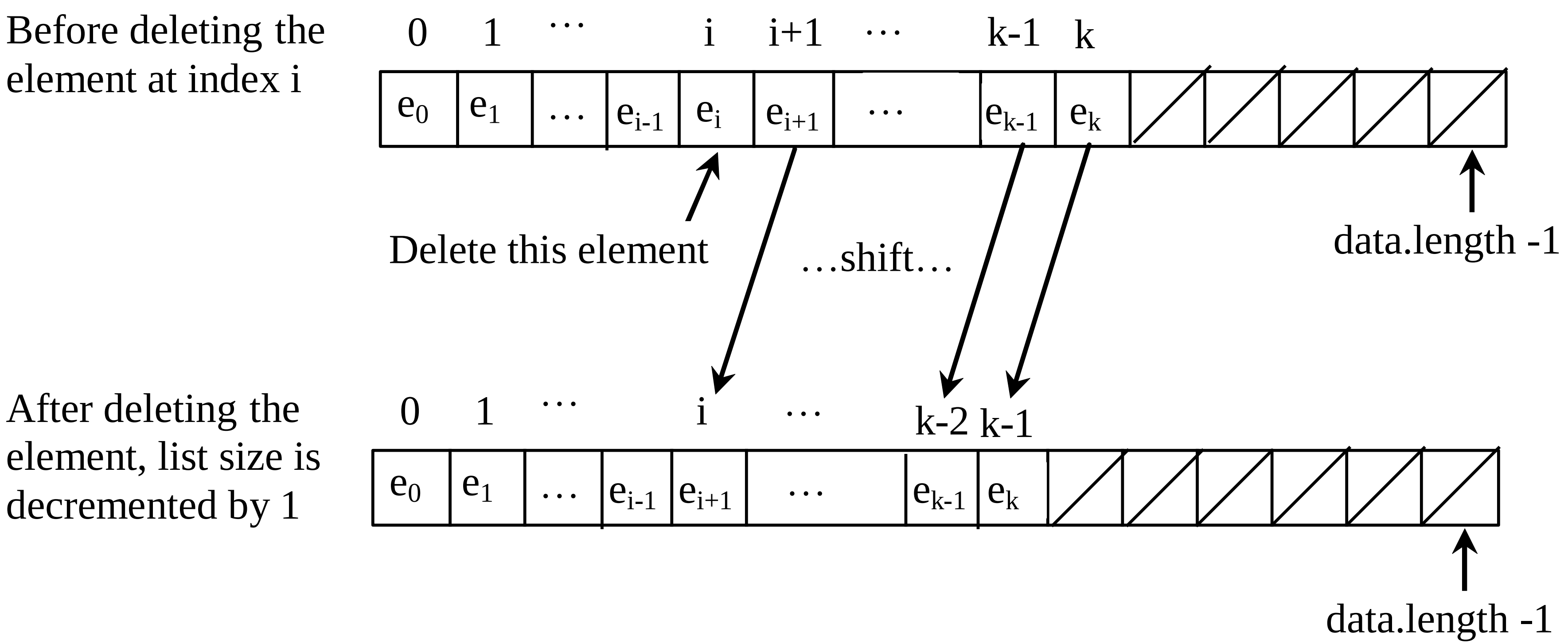
Insertion

- Before inserting a new element at a specified index, shift all the elements after the index to the right and increase the list size by 1

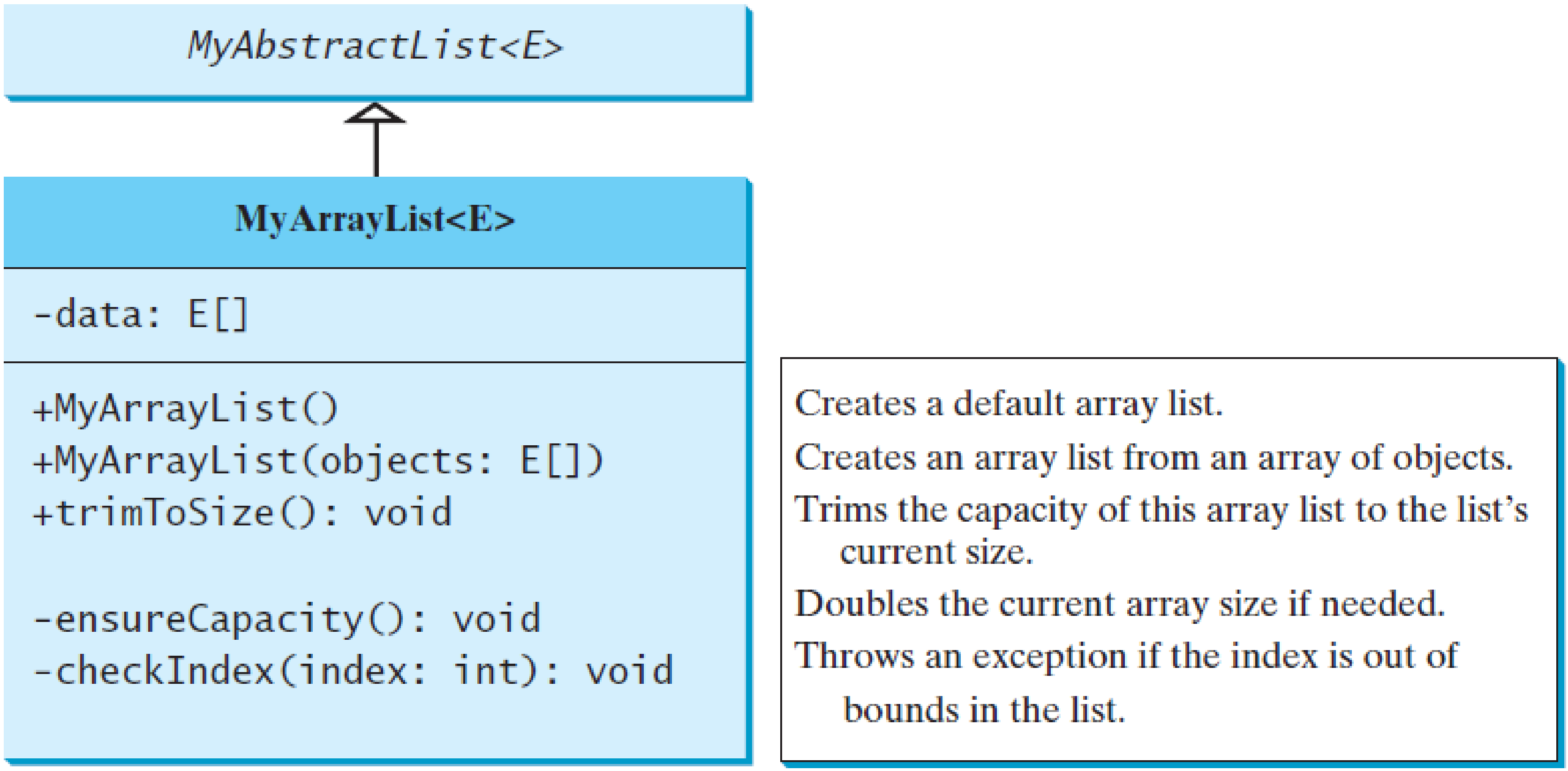


Deletion

- To remove an element at a specified index, shift all the elements after the index to the left by one position and decrease the list size by 1



Implementing MyArrayList



```java
public class MyArrayList<E> extends MyAbstractList<E> {

  public static final int INITIAL_CAPACITY = 16;
  private E[] data = (E[])new Object[INITIAL_CAPACITY];

  /** Create a default list */
  public MyArrayList() {
  }

  /** Create a list from an array of objects */
  public MyArrayList(E[] objects) {
    for (int i = 0; i < objects.length; i++)
      add(objects[i]);
  }

  @Override /** Add a new element at the specified index */
  public void add(int index, E e) {
    ensureCapacity();
    // Move the elements to the right after the specified index
    for (int i = size - 1; i >= index; i--)
      data[i + 1] = data[i];
    // Insert new element to data[index]
    data[index] = e;
    // Increase size by 1
    size++;
  }
```

```java
/** Create a new larger array, double the current size + 1 */
private void ensureCapacity() {
  if (size >= data.length) {
    E[] newData = (E[])(new Object[size * 2 + 1]);
    System.arraycopy(data, 0, newData, 0, size);
    data = newData;
  }
}

@Override /** Clear the list */
public void clear() {
  data = (E[])new Object[INITIAL_CAPACITY];
  size = 0;
}

@Override /** Return true if this list contains the element */
public boolean contains(E e) {
  for (int i = 0; i < size; i++)
    if (e.equals(data[i])) return true;
  return false;
}

@Override /** Return the element at the specified index */
public E get(int index) {
  checkIndex(index);
  return data[index];
}
```

```java
private void checkIndex(int index) {
  if (index < 0 || index >= size)
    throw new IndexOutOfBoundsException
      ("Index: " + index + ", Size: " + size);
}

@Override /** Return the index of the first matching element
 *  in this list. Return -1 if no match. */
public int indexOf(E e) {
  for (int i = 0; i < size; i++)
    if (e.equals(data[i])) return i;
  return -1;
}

@Override /** Return the index of the last matching element
 *  in this list. Return -1 if no match. */
public int lastIndexOf(E e) {
  for (int i = size - 1; i >= 0; i--)
    if (e.equals(data[i])) return i;
  return -1;
}
```

```java
@Override /** Remove the element at the specified position
 *  in this list. Shift any subsequent elements to the left.
 *  Return the element that was removed from the list. */
public E remove(int index) {
  checkIndex(index);
  E e = data[index];
  // Shift data to the left
  for (int j = index; j < size - 1; j++)
    data[j] = data[j + 1];
  data[size - 1] = null; // This element is now null
  // Decrement size
  size--;
  return e;
}

@Override /** Replace the element at the specified position
 *  in this list with the specified element. */
public E set(int index, E e) {
  checkIndex(index);
  E old = data[index];
  data[index] = e;
  return old;
}
```

```
@Override
public String toString() {
  StringBuilder result = new StringBuilder(size*5).append("[");
  for (int i = 0; i < size; i++) {
    result.append(data[i]);
    if (i < size - 1) result.append(", ");
  }
  return result.append("]").toString();
}

/** Trims the capacity to current size */
public void trimToSize() {
  if (size != data.length) {
    E[] newData = (E[])(new Object[size]);
    System.arraycopy(data, 0, newData, 0, size);
    data = newData;
  } // If size == capacity, no need to trim
}

@Override /** Override iterator() defined in Iterable */
public java.util.Iterator<E> iterator() {
  return new ArrayListIterator();
}
```

```
  private class ArrayListIterator
      implements java.util.Iterator<E> {
    private int current = 0; // Current index
    @Override
    public boolean hasNext() {
      return (current < size);
    }
    @Override
    public E next() {
      return data[current++];
    }
    @Override
    public void remove() {
      remove(current);
    }
  }

}
```

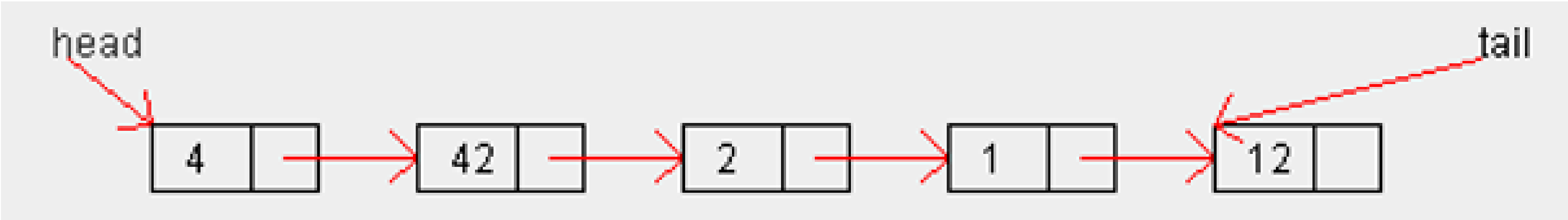
```java
public class TestMyArrayList {
  public static void main(String[] args) {
    // Create a list
    MyList<String> list = new MyArrayList<String>();

    // Add elements to the list
    list.add("America"); // Add it to the list
    System.out.println("(1) " + list);

    list.add(0, "Canada"); // Add it to the beginning of the list
    System.out.println("(2) " + list);

    list.add("Russia"); // Add it to the end of the list
    System.out.println("(3) " + list);

    list.add("France"); // Add it to the end of the list
    System.out.println("(4) " + list);

    list.add(2, "Germany"); // Add it to the list at index 2
    System.out.println("(5) " + list);

    list.add(5, "Norway"); // Add it to the list at index 5
    System.out.println("(6) " + list);
```

```java
    // Remove elements from the list
    list.remove("Canada"); // Same as list.remove(0) in this case
    System.out.println("(7) " + list);

    list.remove(2); // Remove the element at index 2
    System.out.println("(8) " + list);

    list.remove(list.size() - 1); // Remove the last element
    System.out.print("(9) " + list + "\n(10) ");

    // enhanced-for loops require that the Collection implements
    //  Iterable or is an array
    for (String s: list)
      System.out.print(s.toUpperCase() + " ");
  }
}
```

```
(1) [America]
(2) [Canada, America]
(3) [Canada, America, Russia]
(4) [Canada, America, Russia, France]
(5) [Canada, America, Germany, Russia, France]
(6) [Canada, America, Germany, Russia, France, Norway]
(7) [America, Germany, Russia, France, Norway]
(8) [America, Germany, France, Norway]
(9) [America, Germany, France]
(10) AMERICA GERMANY FRANCE
```

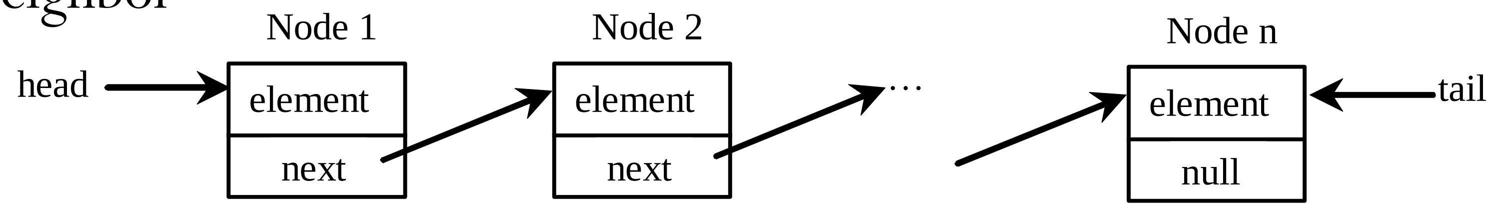
Linked Lists

- Since **`MyArrayList`** is implemented using an array, the methods **`get(int index)`** and **`set(int index, Object o)`** for accessing and modifying an element through an index and the **`add(Object o)`** for adding an element **<u>at the end of the list</u>** are **<u>very efficient</u>**
- However, the methods **`add(int index, Object o)`** and **`remove(int index)`** are **<u>inefficient</u>** because it requires shifting potentially a large number of elements
- You can use a ***<u>linked structure</u>*** to implement a list to improve efficiency for adding and removing an element **<u>anywhere</u>** in a list



Nodes in Linked Lists

- A linked list **consists of nodes**
  - Each node contains an element, and each node is linked to its next neighbor



  - Thus a node can be defined as a class, as follows:

```
class Node<E> {
  E element;
  Node<E> next;

  public Node(E o) {
    element = o;
  }
}
```

Empty list

- The variable **`head`** refers to the first node in the list, and the variable **`tail`** refers to the last node in the list
  - If the list is empty, both are null

Step 1: Declare <u>head</u> and <u>tail</u>:

```
Node<String> head = null;
Node<String> tail = null;
```

The list is empty now

Adding Nodes

Step 2: Create the first node and insert it to the list:

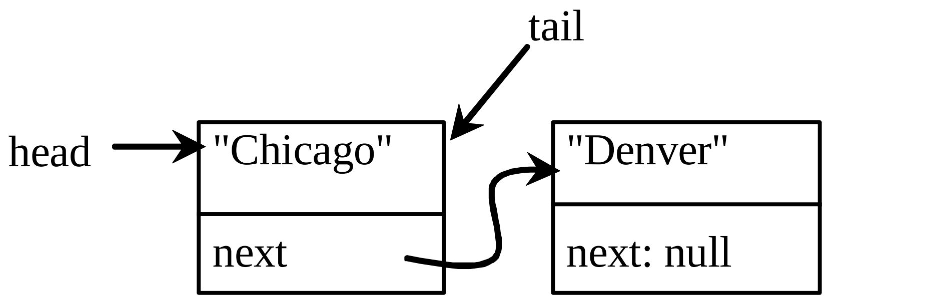
```
head = new Node<>("Chicago");
tail = head;
```

After the first node is inserted

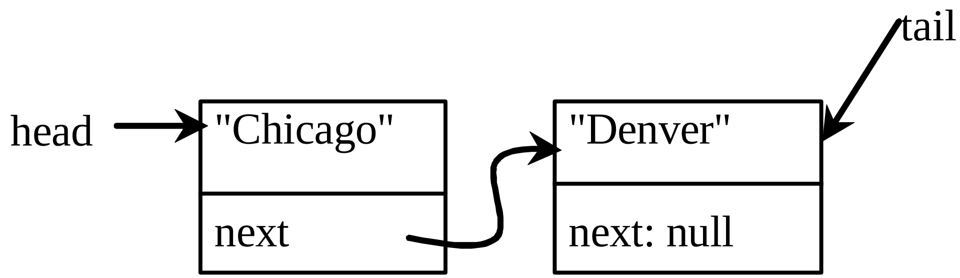
Adding Nodes

Step 3: Create the second node and insert it to the list:

tail.next = **new** Node<>("Denver");



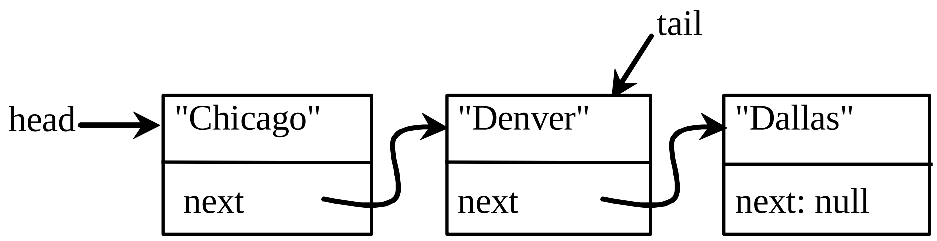
tail = tail.next;



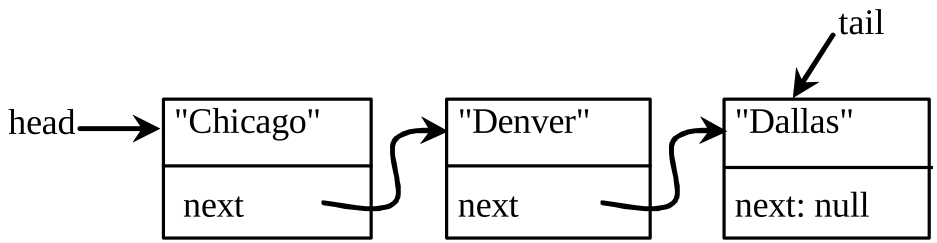
Adding More Nodes is the same

Create the third node and insert it to the list:

```
tail.next =
  new Node<>("Dallas");
```




```
tail = tail.next;
```

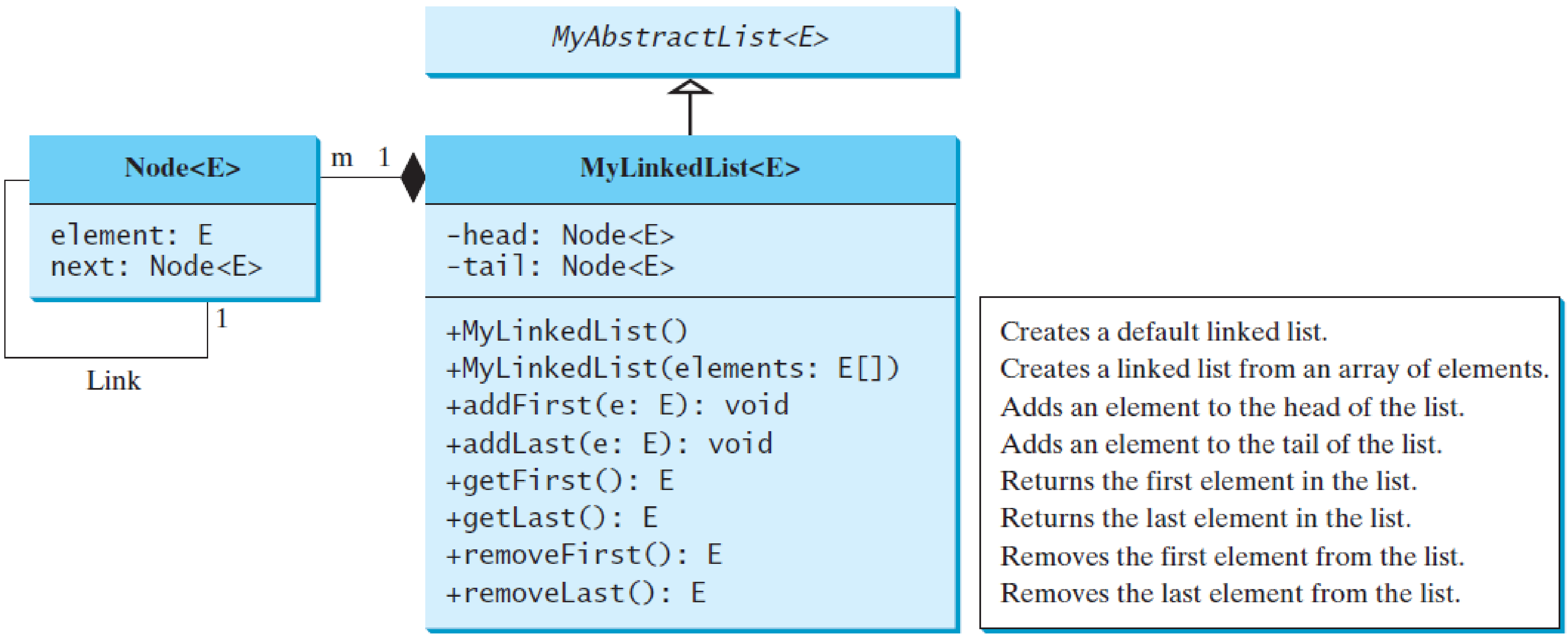


Traversing All Elements in the List

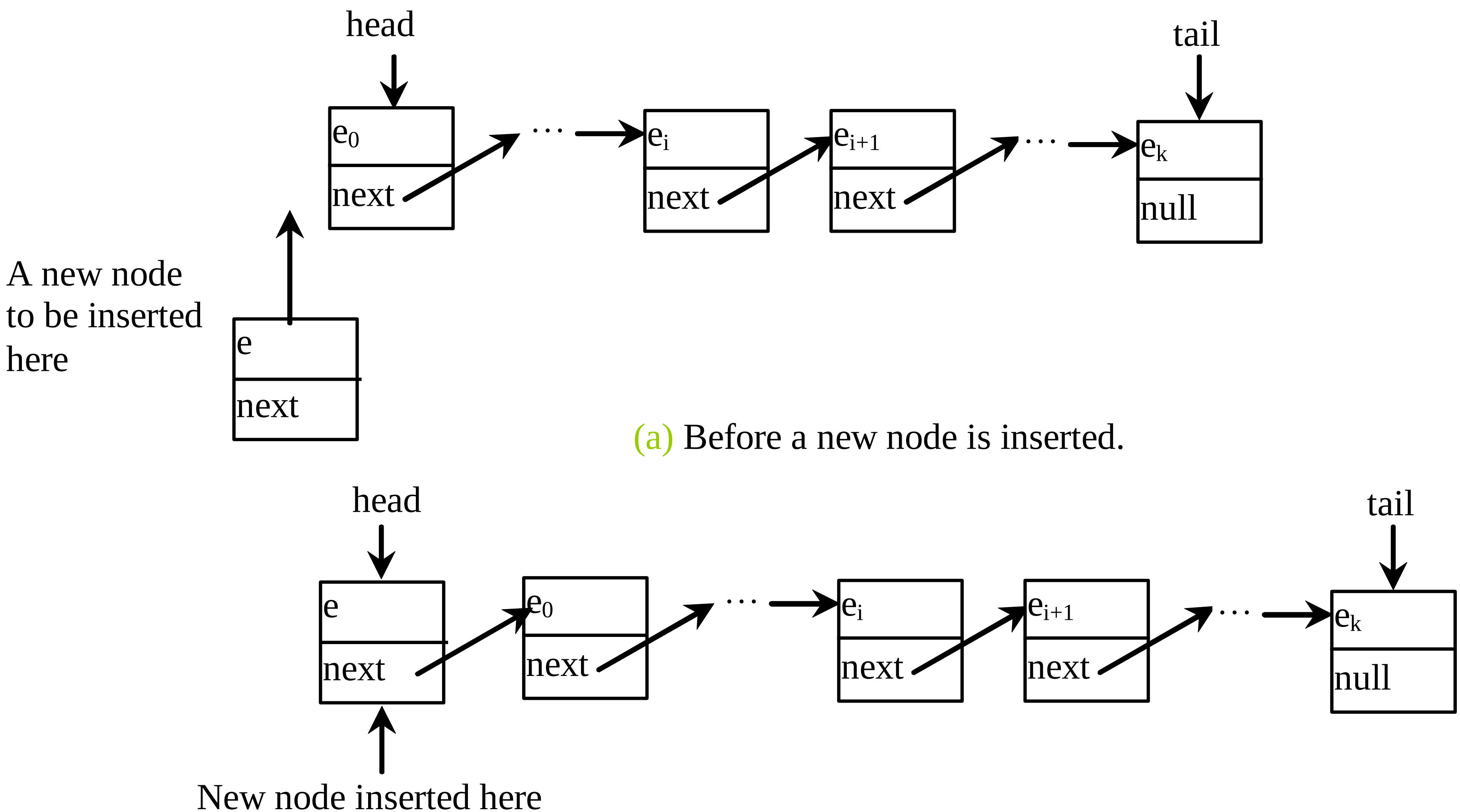
- Each node contains the element and a data field named **`next`** that points to the next node
  - If the node is the last in the list, its pointer data field **`next`** contains the value **`null`** (You can use this property to detect the last node)
  - For example, you may write the following loop to traverse all the nodes in the list:

```
Node<E> current = head;
while (current != null) {
  System.out.println(current.element);
  current = current.next;
}
```

MyLinkedList



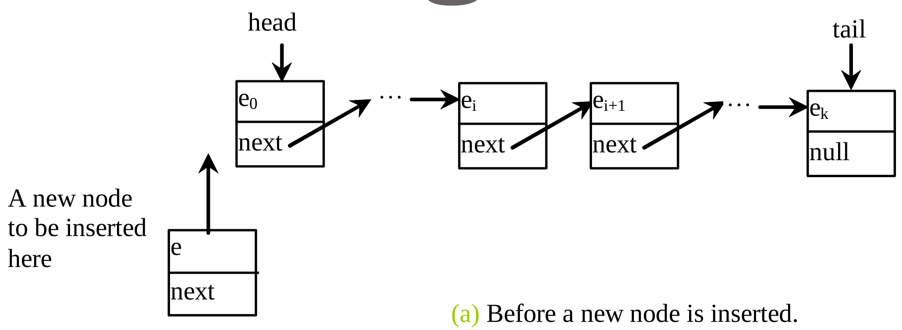
Implementing `addFirst(E e)`



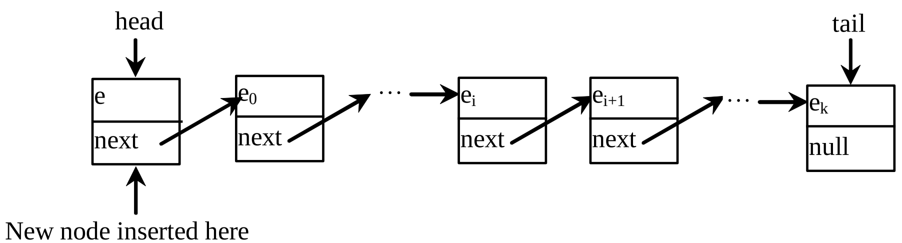
(a) Before a new node is inserted.

(b) After a new node is inserted.

Implementing `addFirst(E e)`



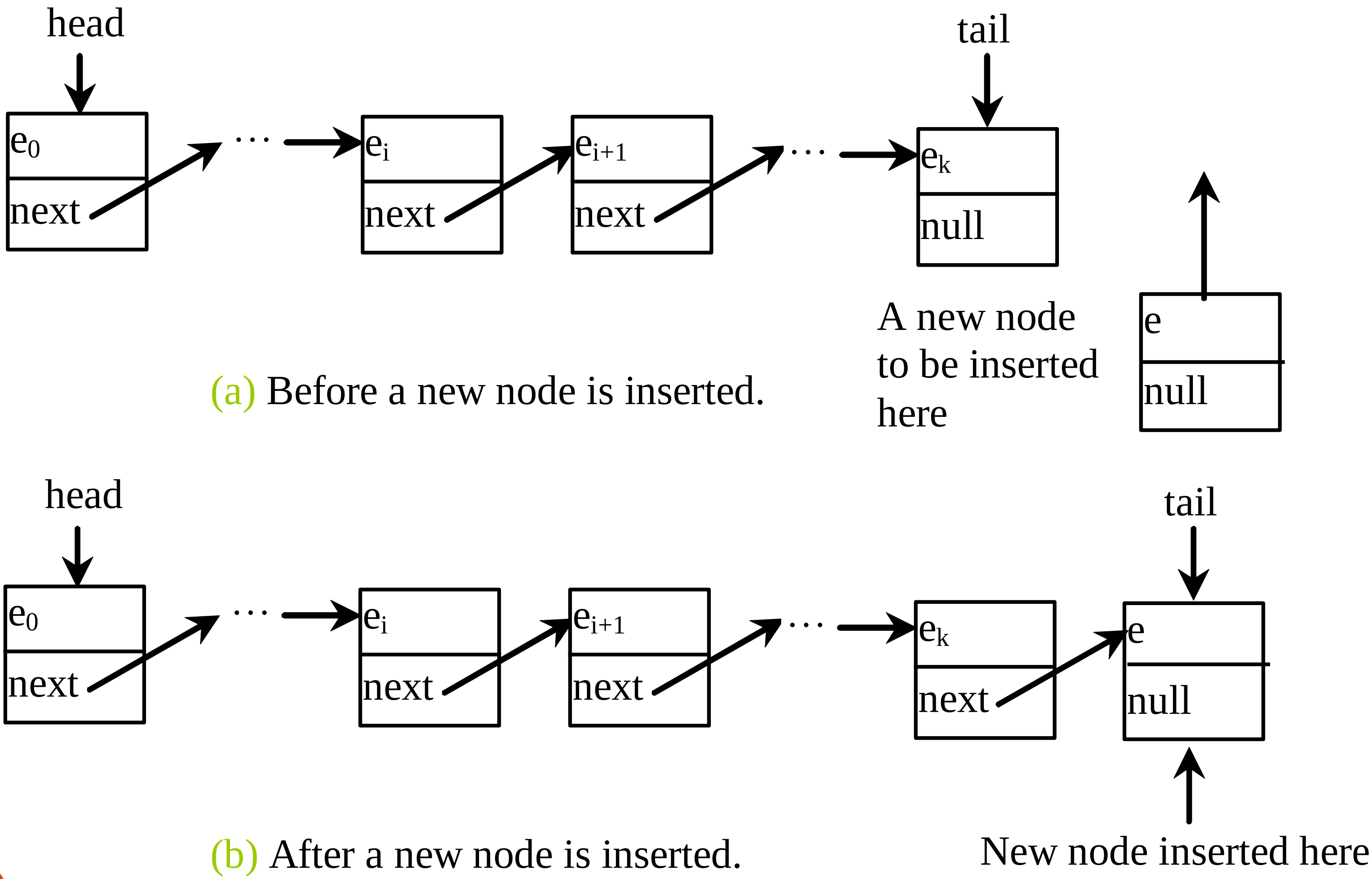
(a) Before a new node is inserted.



(b) After a new node is inserted.

```
public void addFirst(E e) {
  Node<E> newNode = new Node<>(e);
  newNode.next = head;
  head = newNode;
  size++;
  if (tail == null)
    tail = head;
}
```

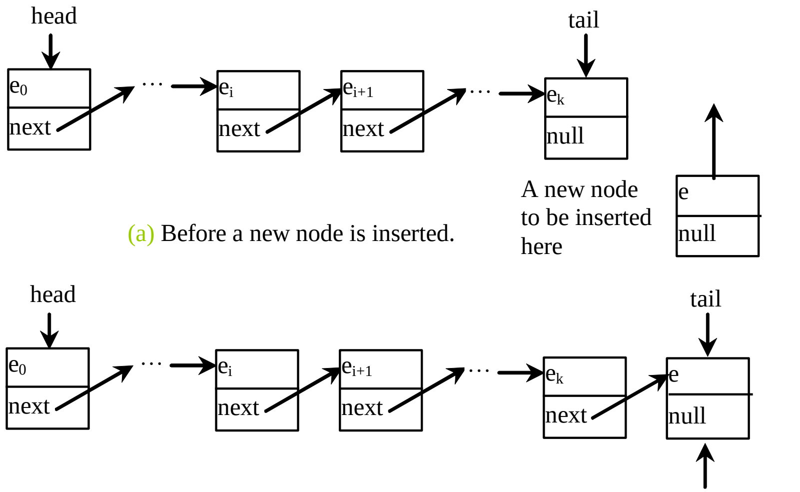
Implementing `addLast(E e)`



(a) Before a new node is inserted.

(b) After a new node is inserted.

Implementing `addLast(E e)`

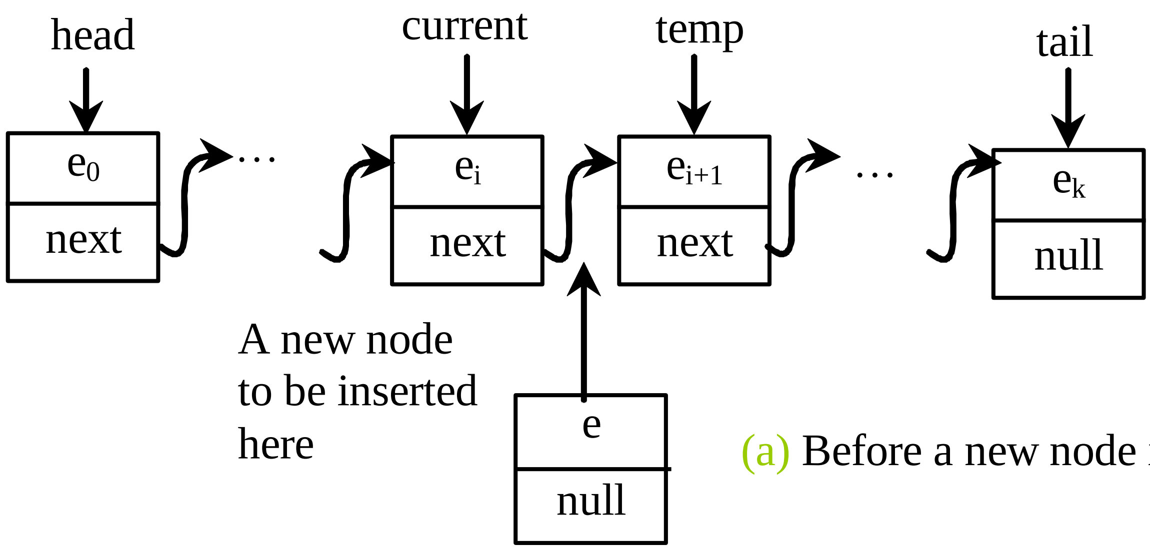


(a) Before a new node is inserted.

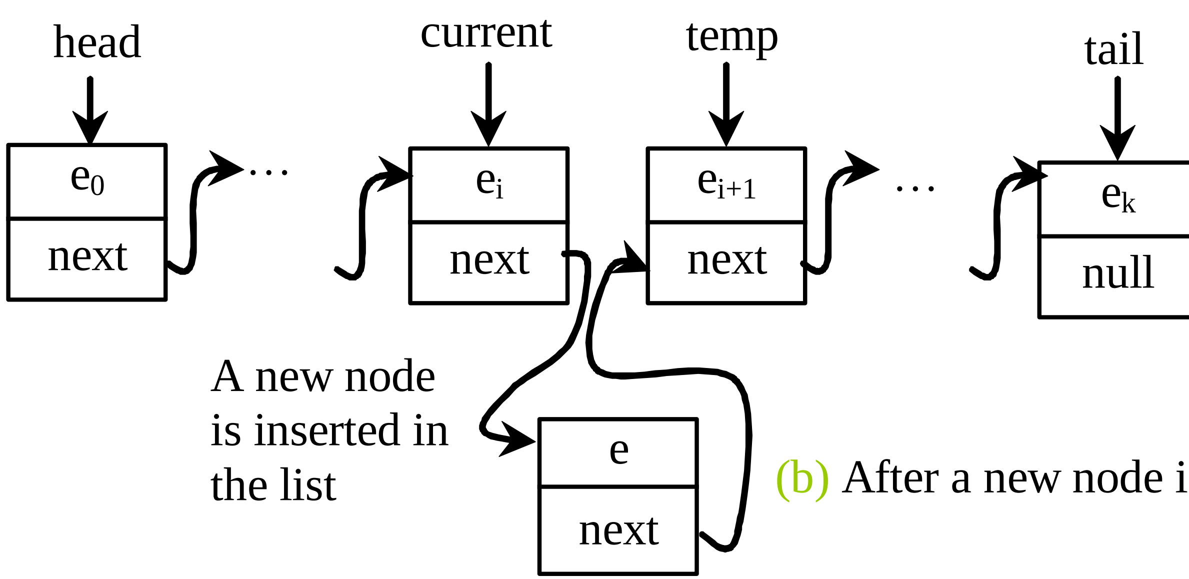
(b) After a new node is inserted.

```
public void addLast(E e) {
  if (tail == null) {
    head = tail = new Node<>(e);
  } else {
    tail.next = new Node<>(e);
    tail = tail.next;
  }
  size++;
}
```

Implementing `add(int index, E e)`



(a) Before a new node is inserted.

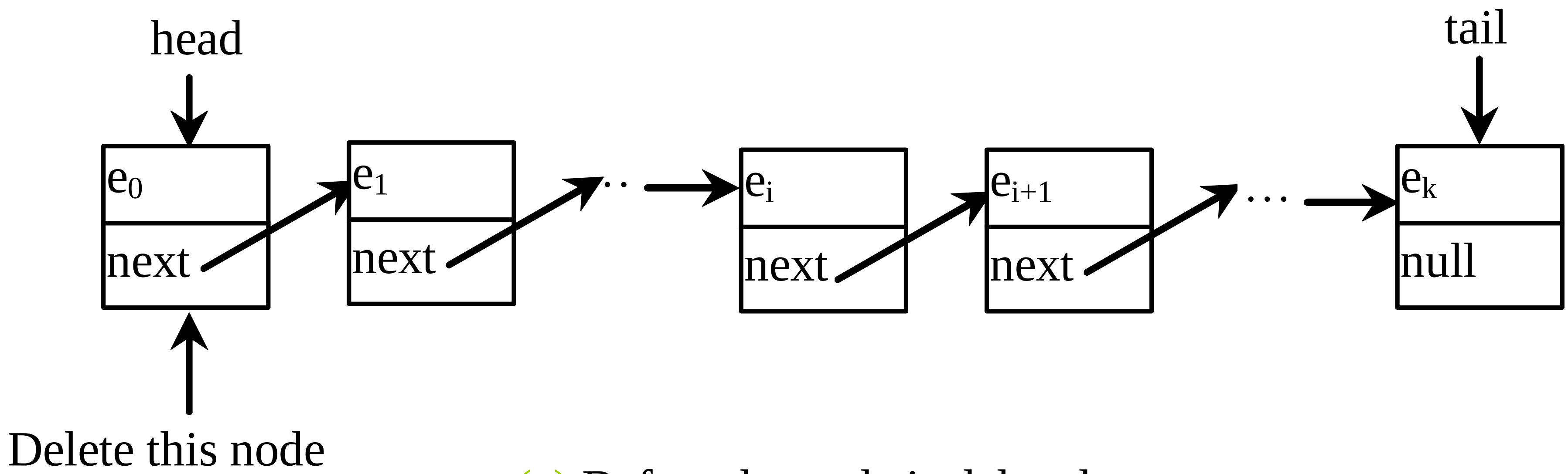


(b) After a new node is inserted.

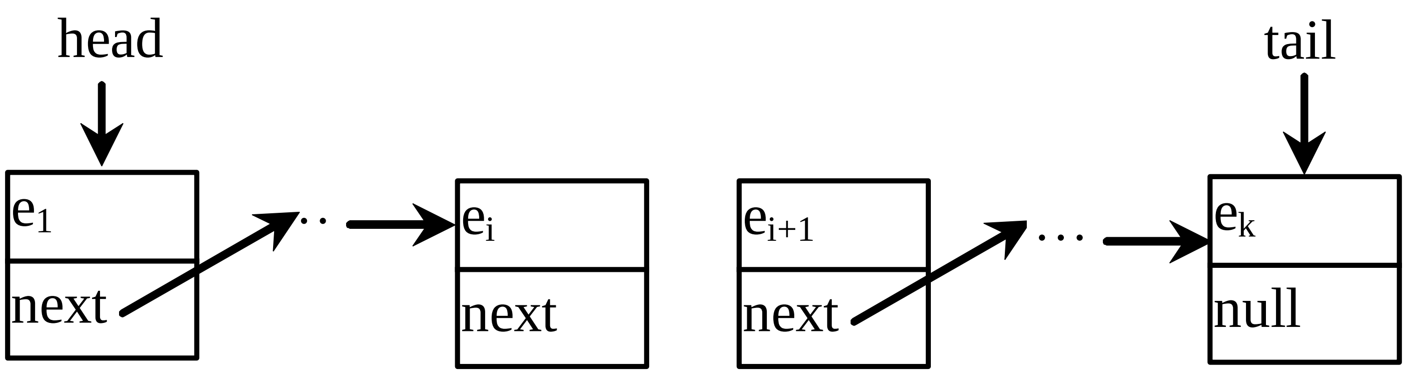
Implementing **add(int index, E e)**

```
public void add(int index, E e) {
  if (index == 0) addFirst(e);
  else if (index >= size) addLast(e);
  else {
    Node<E> current = head;
    for (int i = 1; i < index; i++)
      current = current.next;
    Node<E> temp = current.next;
    current.next = new Node<>(e);
    (current.next).next = temp;
    size++;
  }
}
```

Implementing `removeFirst()`

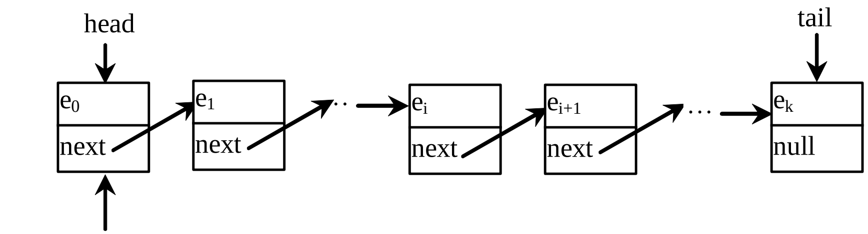


(a) Before the node is deleted.

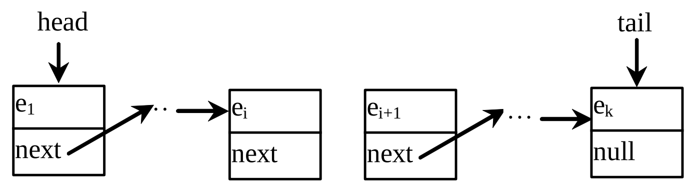


(b) After the first node is deleted

Implementing `removeFirst()`



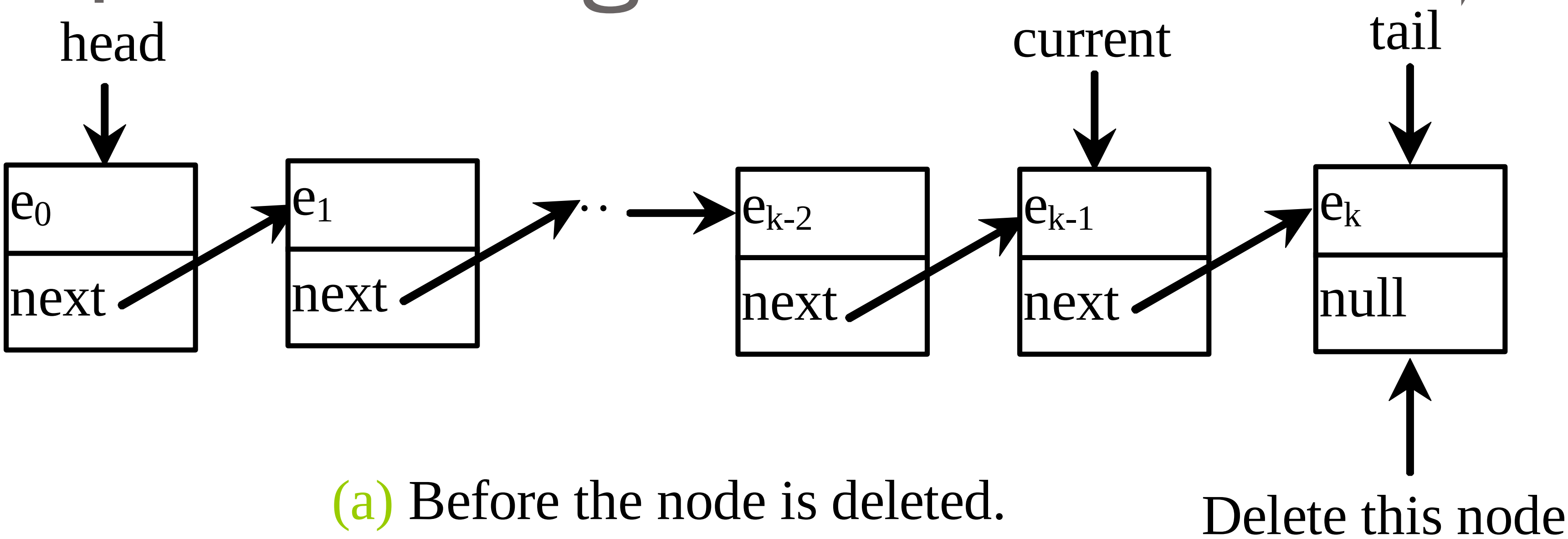
(a) Before the node is deleted.



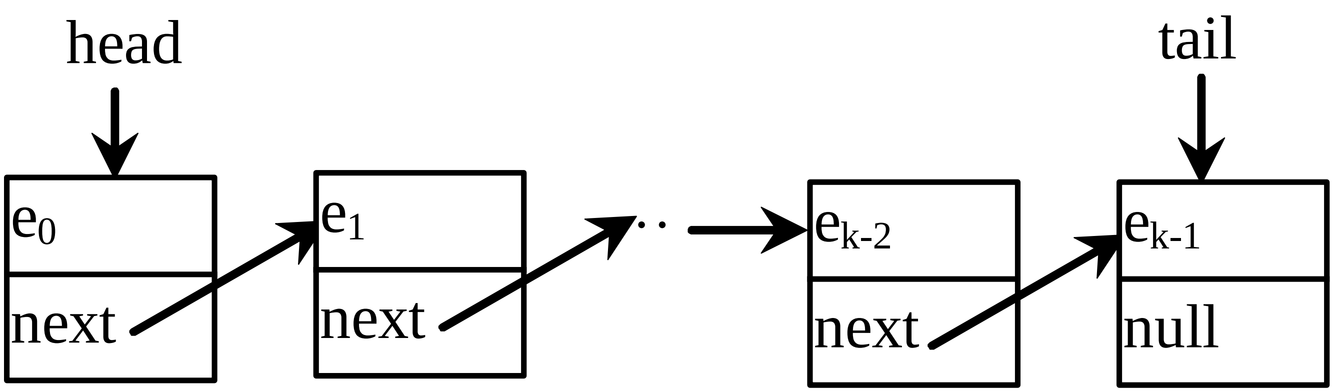
(b) After the first node is deleted

```
public E removeFirst() {
  if (size == 0) return null;
  else {
    Node<E> temp = head;
    head = head.next;
    size--;
    if (head == null) tail = null;
    return temp.element;
  }
}
```

Implementing `removeLast()`



(a) Before the node is deleted.

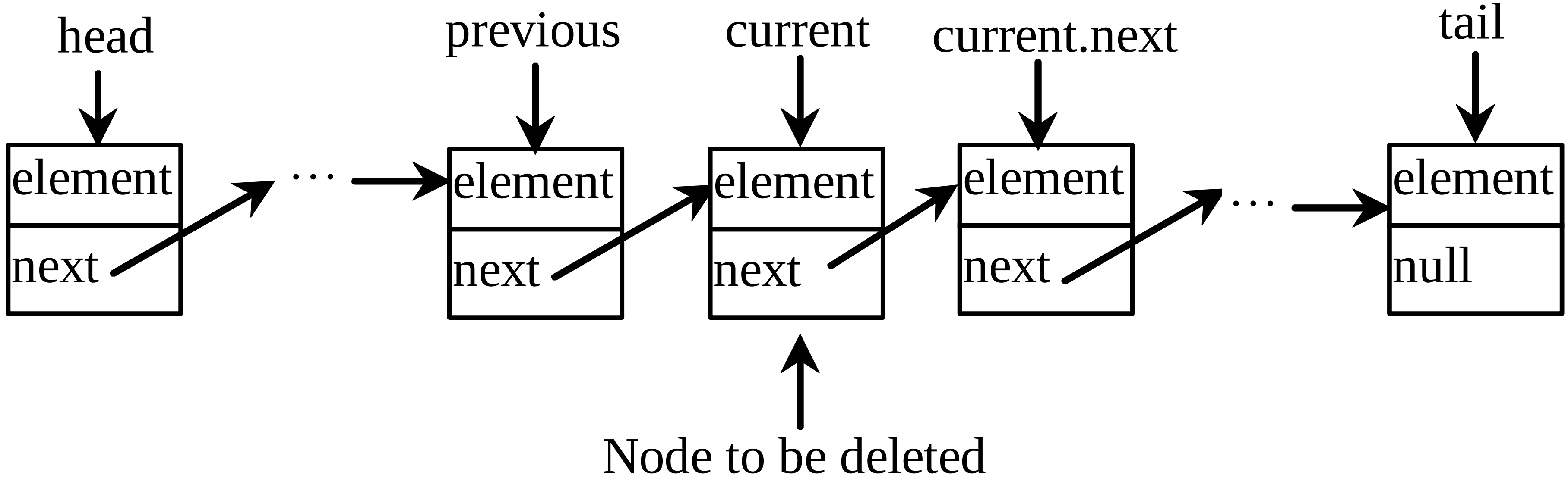


(b) After the last node is deleted

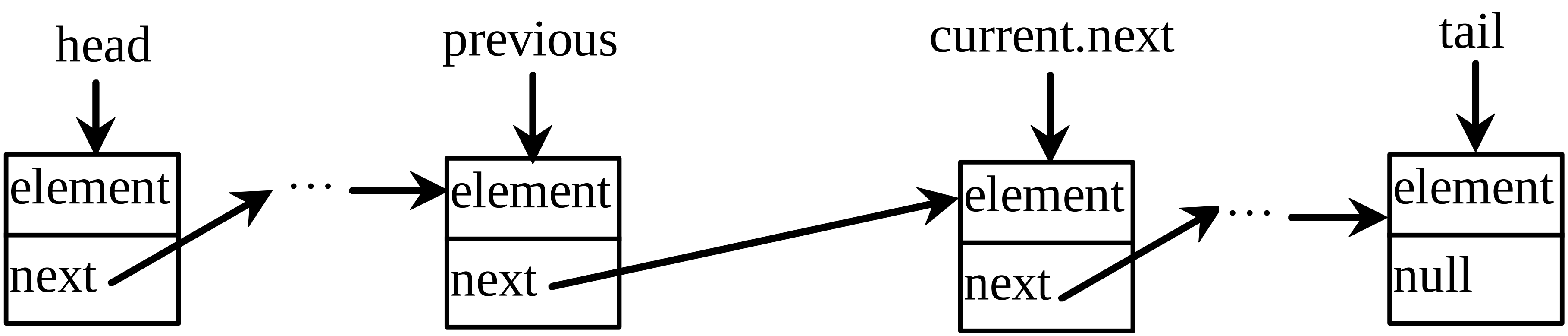
Implementing `removeLast()`

```
public E removeLast() {
  if (size == 0) return null;
  else if (size == 1) {
    Node<E> temp = head;
    head = tail = null;
    size = 0;
    return temp.element;
  } else {
    Node<E> current = head;
    for (int i = 0; i < size - 2; i++)
      current = current.next;
    Node<E> temp = tail;
    tail = current;
    tail.next = null;
    size--;
    return temp.element;
  }
}
```

Implementing `remove(int index)`



(a) Before the node is deleted.



(b) After the node is deleted.

Implementing `remove(int index)`

```
public E remove(int index) {
  if (index < 0 || index >= size) return null;
  else if (index == 0) return removeFirst();
  else if (index == size - 1) return removeLast();
  else {
    Node<E> previous = head;
    for (int i = 1; i < index; i++) {
      previous = previous.next;
    }
    Node<E> current = previous.next;
    previous.next = current.next;
    size--;
    return current.element;
  }
}
```

```java
public class MyLinkedList<E> extends MyAbstractList<E> {
  private Node<E> head, tail;

  /** Create a default list */
  public MyLinkedList() {
  }
  /** Create a list from an array of objects */
  public MyLinkedList(E[] objects) {
    super(objects);
  }

  private static class Node<E> {
    E element;
    Node<E> next;
    public Node(E element) {
      this.element = element;
    }
  }
```

```java
/** Return the head element in the list */
public E getFirst() {
  if (size == 0) {
    return null;
  } else {
    return head.element;
  }
}

/** Return the last element in the list */
public E getLast() {
  if (size == 0) {
    return null;
  } else {
    return tail.element;
  }
}
```

```java
/** Add an element to the beginning of the list */
public void addFirst(E e) {
  Node<E> newNode = new Node<E>(e); // Create a new node
  newNode.next = head; // link the new node with the head
  head = newNode; // head points to the new node
  size++; // Increase list size
  if (tail == null) // the new node is the only node in list
    tail = head;
}

/** Add an element to the end of the list */
public void addLast(E e) {
  Node<E> newNode = new Node<E>(e); // Create a new for element e
  if (tail == null) {
    head = tail = newNode; // The new node is the only node in list
  } else {
    tail.next = newNode; // Link the new with the last node
    tail = tail.next; // tail now points to the last node
  }
  size++; // Increase size
}
```

```
/** Add a new element at the specified index in this list
 * The index of the head element is 0 */
public void add(int index, E e) {
  if (index == 0) {
    addFirst(e);
  } else if (index >= size) {
    addLast(e);
  } else {
    Node<E> current = head;
    for (int i = 1; i < index; i++) {
      current = current.next;
    }
    Node<E> temp = current.next;
    current.next = new Node<E>(e);
    (current.next).next = temp;
    size++;
  }
}
```

```
/** Remove the head node and
 *  return the object that is contained in the removed
 * node. */
public E removeFirst() {
  if (size == 0) {
    return null;
  } else {
    Node<E> temp = head;
    head = head.next;
    size--;
    if (head == null) {
      tail = null;
    }
    return temp.element;
  }
}
```

```java
/** Remove the last node and
 * return the object that is contained in the removed node. */
public E removeLast() {
  if (size == 0) {
    return null;
  } else if (size == 1) {
    Node<E> temp = head;
    head = tail = null;
    size = 0;
    return temp.element;
  } else {
    Node<E> current = head;
    for (int i = 0; i < size - 2; i++) {
      current = current.next;
    }
    Node<E> temp = tail;
    tail = current;
    tail.next = null;
    size--;
    return temp.element;
  }
}
```

```java
/** Remove the element at the specified position in this list.
 *  Return the element that was removed from the list. */
public E remove(int index) {
  if (index < 0 || index >= size) {
    return null;
  } else if (index == 0) {
    return removeFirst();
  } else if (index == size - 1) {
    return removeLast();
  } else {
    Node<E> previous = head;
    for (int i = 1; i < index; i++) {
      previous = previous.next;
    }
    Node<E> current = previous.next;
    previous.next = current.next;
    size--;
    return current.element;
  }
}
```

```
@Override /** Override toString() to return elements in the list */
public String toString() {
  StringBuilder result = new StringBuilder("[");
  Node<E> current = head;
  for (int i = 0; i < size; i++) {
    result.append(current.element);
    current = current.next;
    if (current != null) {
     result.append(", "); // Separate two elements with a comma
    } else {
     result.append("]"); // Insert the closing ] in the string
    }
  }
  return result.toString();
}

/** Clear the list */
public void clear() {
  head = tail = null;
}
```

```
/** Return true if this list contains the element o */
public boolean contains(E e) {
  Node<E> current = head;
  while(current != null) {
    if (current.element.equals(E))
      return true;
    current = current.next;
  }
  return false;
}

//public boolean contains(E e) {
//  Node<E> current = head;
//  for (int i = 0; i < size; i++) {
//    if (current.element.equals(E))
//      return true;
//    current = current.next;
//  }
//  return false;
//}
```

```
/** Return the element from this list at the specified index */
public E get(int index) {
  if(size <= index)
    return null;
  int i = 0;
  Node<E> current = head;
  for(int i=0; i<index; i++)
    current = current.next;
  return current.element;
}
```

```
/** Return the index of the head matching element in this list.
 *  Return -1 if no match. */
public int indexOf(E e) {
  Node<E> current = head;
  int i = 0;
  while(current != null) {
    if (current.element.equals(E))
      return i;
    i++;
    current = current.next;
  }
  return -1;
}

/** Return the index of the last matching element in this list
 *  Return -1 if no match. */
public int lastIndexOf(E e) {
  Node<E> current = head;
  int i = 0, lastIndex = -1;
  while(current != null) {
    if (current.element.equals(E))
      lastIndex = i;
    i++;
    current = current.next;
  }
  return lastIndex;
}
```

```java
/** Replace the element at the specified position in this list
 *  with the specified element. */
public E set(int index, E e) {
   if(index >= size)
     return null;
   Node<E> current = head;
   int i = 0;
   for(int i=0; i<index; i++) {
     i++;
     current = current.next;
   }
   E old = current.element;
   current.element = e;
   return old;
  }
```

```java
  @Override
  public Iterator<E> iterator() {
    return new LinkedListIterator();
  }
  private class LinkedListIterator implements java.util.Iterator<E> {
      Node<E> current = head;
      int index = 0;
      @Override
      public boolean hasNext() {
              index++;
              return (current !=null && current != tail);
      }
      @Override
      public E next() {
              Node<E> node = current;
              current = current.next;
              index++;
              return (E) node;
      }
      @Override
      public void remove() {
              remove(index);
      }
  }
}
```

```java
public class TestLinkedList {

  public static void main(String[] args) {
    // Create a list for strings
    MyLinkedList<String> list = new MyLinkedList<String>();

    // Add elements to the list
    list.add("America"); // Add it to the list
    System.out.println("(1) " + list);

    list.add(0, "Canada"); // Add it to the beginning of the list
    System.out.println("(2) " + list);

    list.add("Russia"); // Add it to the end of the list
    System.out.println("(3) " + list);

    list.addLast("France"); // Add it to the end of the list
    System.out.println("(4) " + list);

    list.add(2, "Germany"); // Add it to the list at index 2
    System.out.println("(5) " + list);

    list.add(5, "Norway"); // Add it to the list at index 5
    System.out.println("(6) " + list);
```

```
    list.add(0, "Poland"); // Same as list.addFirst("Poland")
    System.out.println("(7) " + list);

    // Remove elements from the list
    list.remove(0); // Same as list.remove("Australia") in this case
    System.out.println("(8) " + list);

    list.remove(2); // Remove the element at index 2
    System.out.println("(9) " + list);

    list.remove(list.size() - 1); // Remove the last element
    System.out.println("(10) " + list);
  }
}
```

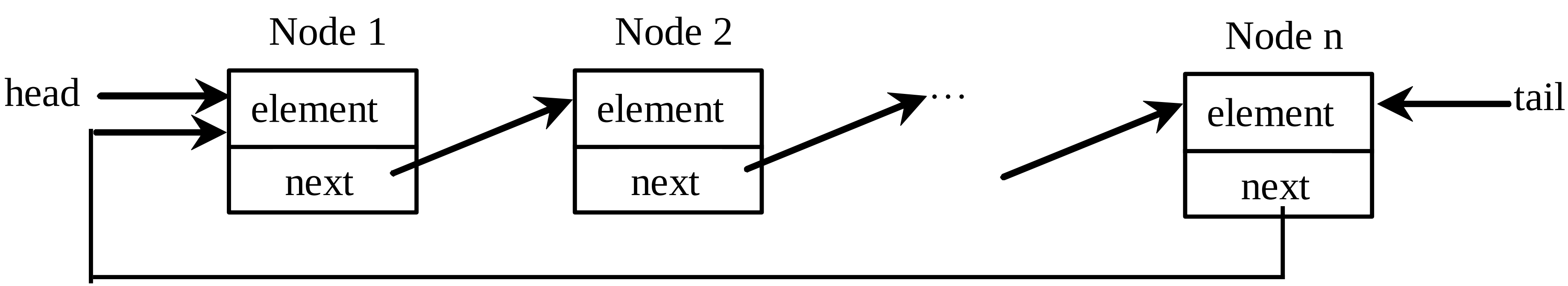
```
    (1) [America]
    (2) [Canada, America]
    (3) [Canada, America, Russia]
    (4) [Canada, America, Russia, France]
    (5) [Canada, America, Germany, Russia, France]
    (6) [Canada, America, Germany, Russia, France, Norway]
    (7) [Poland, Canada, America, Germany, Russia, France, Norway]
    (8) [Canada, America, Germany, Russia, France, Norway]
    (9) [Canada, America, Russia, France, Norway]
    (10) [Canada, America, Russia, France]
    (11) CANADA AMERICA RUSSIA FRANCE
```

(Worse) Time Complexity for **`ArrayList`** and **`LinkedList`**

Methods	MyArrayList/ArrayList	MyLinkedList/LinkedList
`add(e: E)`	$O(1)$	$O(1)$
`add(index: int, e: E)`	$O(n)$	$O(n)$
`clear()`	$O(1)$	$O(1)$
`contains(e: E)`	$O(n)$	$O(n)$
`get(index: int)`	$O(1)$	$O(n)$
`indexOf(e: E)`	$O(n)$	$O(n)$
`isEmpty()`	$O(1)$	$O(1)$
`lastIndexOf(e: E)`	$O(n)$	$O(n)$
`remove(e: E)`	$O(n)$	$O(n)$
`size()`	$O(1)$	$O(1)$
`remove(index: int)`	$O(n)$	$O(n)$
`set(index: int, e: E)`	$O(1)$	$O(n)$
`addFirst(e: E)`	$O(n)$	$O(1)$
`removeFirst()`	$O(n)$	$O(1)$

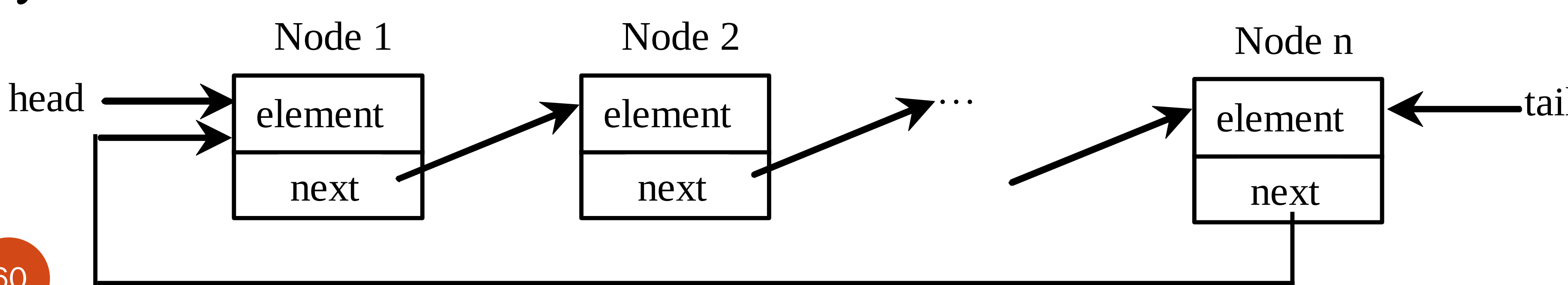
Circular Linked Lists

- A ***circular singly linked list*** is a singly linked list, with the exception that the pointer of the last node points back to the first node



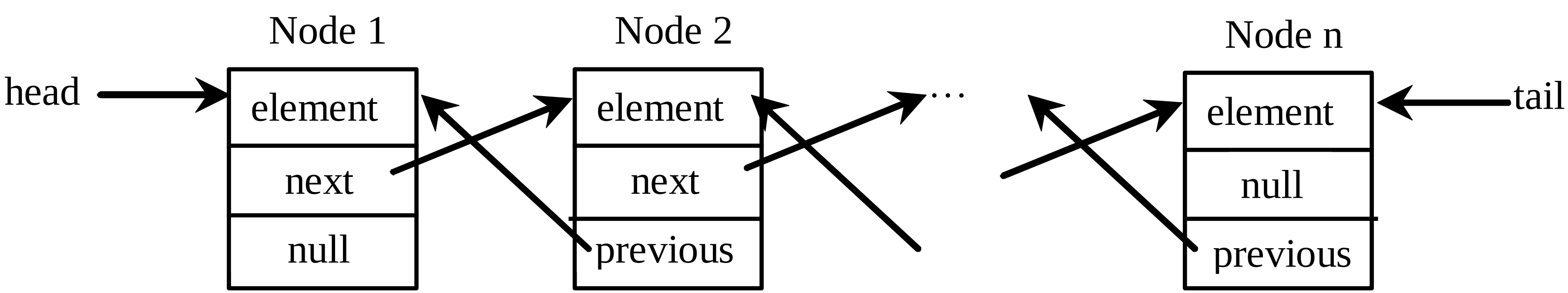
Circular Linked Lists

```
public void addFirst(E e) {
  Node<E> newNode = new Node<>(e);
  newNode.next = head;
  head = newNode;
  size++;
  if (tail == null)
    tail = head;
  tail.next = head;
}
```



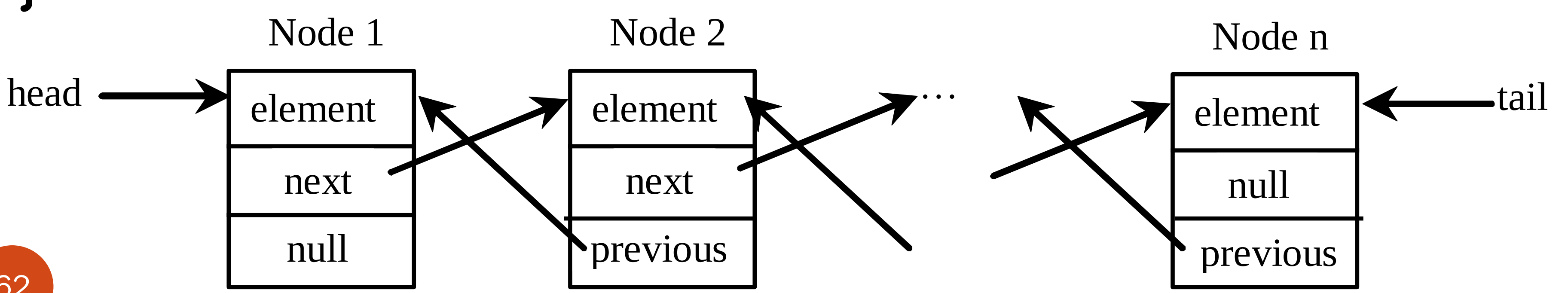
Doubly Linked Lists

- A ***doubly linked list*** contains the nodes with two pointers: one points to the next node and the other points to the previous node
  - These two pointers are conveniently called a ***forward pointer*** and a ***backward pointer***
  - A doubly linked list can be traversed ***forward*** and ***backward***



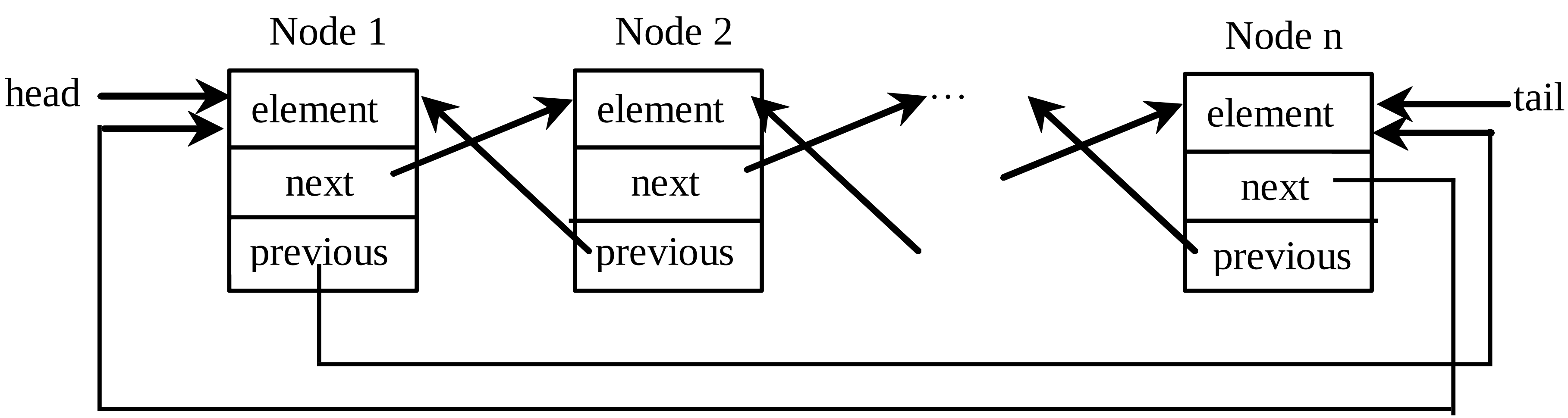
Doubly Linked Lists

```
public void addFirst(E e) {
   Node<E> newNode = new Node<>(e);
   newNode.next = head;
   head = newNode;
   head.next.previous = head;
   size++;
   if (tail == null)
      tail = head;
}
```



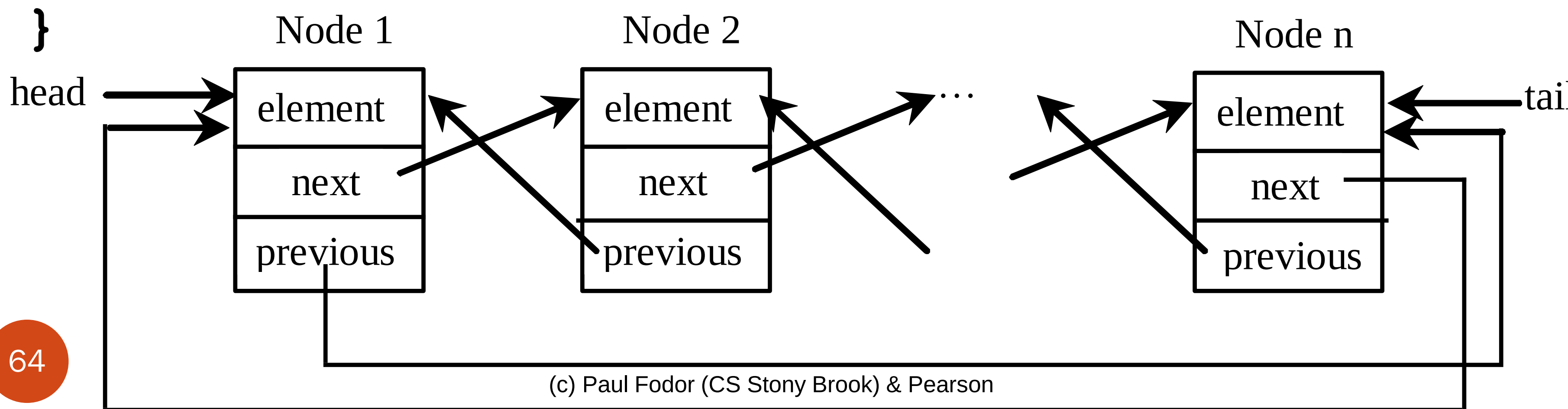
Circular Doubly Linked Lists

- ***A circular doubly linked list*** is doubly linked list, with the exception that the forward pointer of the last node points to the first node and the backward pointer of the first pointer points to the last node:



Circular Doubly Linked Lists

```
public void addFirst(E e) {
  Node<E> newNode = new Node<>(e);
  newNode.next = head;
  head = newNode;
  head.next.previous = head;
  size++;
  if (tail == null)
    tail = head;
  tail.next = head;
}
```



Same Time Complexity for CircularLinkedLists, DoubleLinkedLists and CircularDoubleLinkedLists

Methods	MyLinkedList/LinkedList
add(e: E)	$O(1)$
add(index: int, e: E)	$O(n)$
clear()	$O(1)$
contains(e: E)	$O(n)$
get(index: int)	$O(n)$
indexOf(e: E)	$O(n)$
isEmpty()	$O(1)$
lastIndexOf(e: E)	$O(n)$
remove(e: E)	$O(n)$
size()	$O(1)$
remove(index: int)	$O(n)$
set(index: int, e: E)	$O(n)$
addFirst(e: E)	$O(1)$
removeFirst()	$O(1)$

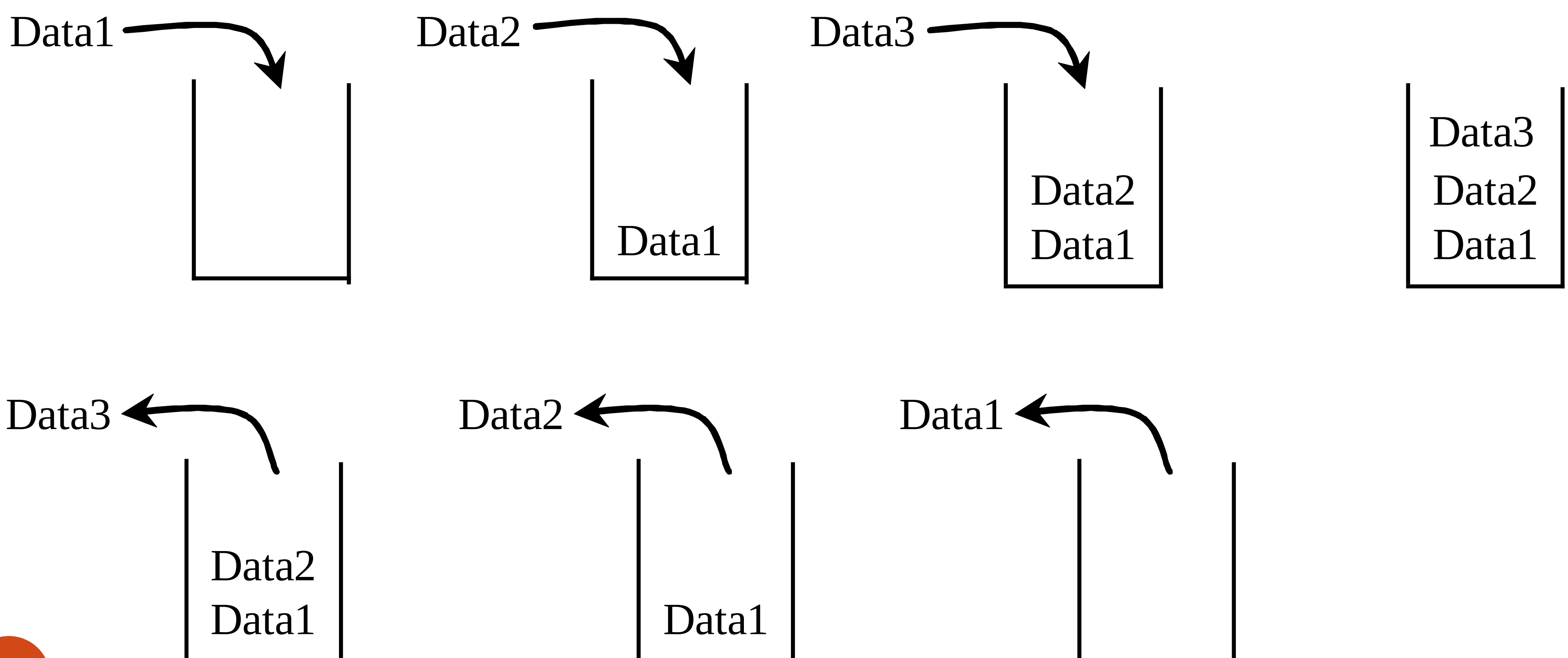
better complexity

for removeLast for

Double LinkedLists

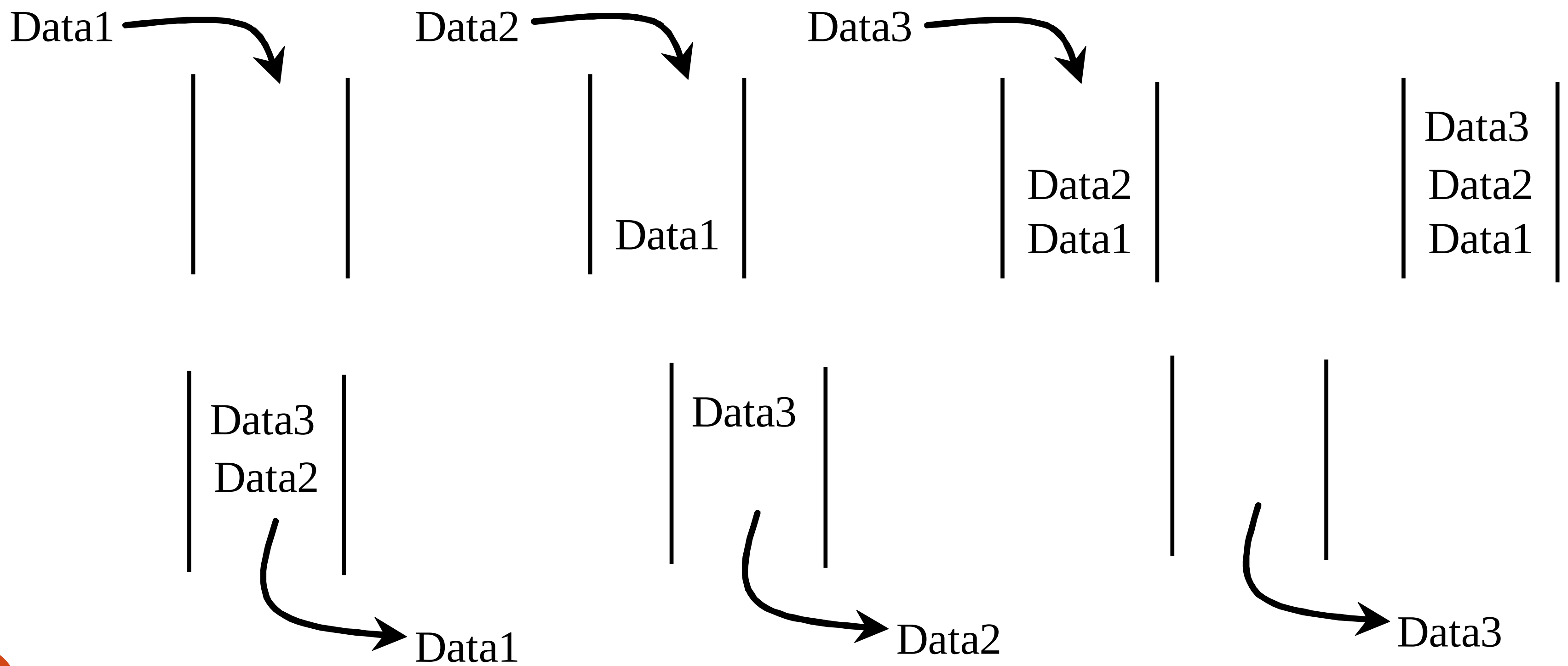
Stacks

- A stack can be viewed as a special type of list, where the elements are accessed, inserted, and deleted only from the end, called the ***top***, of the stack



Queues

- A queue can be viewed as a special type of list, where the elements are inserted into the end (**`tail`**) of the queue, and are accessed and deleted from the beginning (**`head`**) of the queue
  - Example: the customer orders at Starbucks

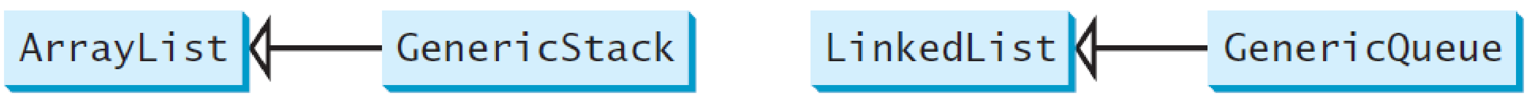


Implementing Stacks and Queues

- Use an array list to implement Stack
  - Since the insertion and deletion operations on a stack are made only at the end of the stack, using an array list to implement a stack is more efficient than a linked list
- Use a linked list to implement Queue
  - Since deletions are made at the beginning of the list, it is more efficient to implement a queue using a linked list than an array list

Design of the Stack and Queue Classes

- There are two ways to design the stack and queue classes:
  - Using **<u>inheritance</u>**: define the stack class by extending the array list class, and the queue class by extending the linked list class



(a) Using inheritance

  - Using **<u>composition</u>**: define an array list as a data field in the stack class, and a linked list as a data field in the queue class

(b) Using composition

Composition is Better

- Both designs are fine, but using composition is better because it enables you to define a complete new stack class and queue class **without inheriting the unnecessary and inappropriate methods from the array list and linked list**

GenericStack and GenericQueue

GenericStack<E>	
-list: java.util.ArrayList<E>	An array list to store elements.
+GenericStack()	Creates an empty stack.
+getSize(): int	Returns the number of elements in this stack.
+peek(): E	Returns the top element in this stack.
+pop(): E	Returns and removes the top element in this stack.
+push(o: E): void	Adds a new element to the top of this stack.
+isEmpty(): boolean	Returns true if the stack is empty.

GenericQueue<E>	
-list: LinkedList<E>	
+enqueue(e: E): void	Adds an element to this queue.
+dequeue(): E	Removes an element from this queue.
+getSize(): int	Returns the number of elements from this queue.

```java
public class GenericStack<E> {
  private java.util.ArrayList<E> list = new java.util.ArrayList<>();

  public int getSize() {
    return list.size();
  }

  public E peek() {
    return list.get(getSize() - 1);
  }

  public void push(E o) {
    list.add(o);
  }
  public E pop() {
    E o = list.get(getSize() - 1);
    list.remove(getSize() - 1);
    return o;
  }
  public boolean isEmpty() {
    return list.isEmpty();
  }
  @Override
  public String toString() {
    return "stack: " + list.toString();
  }
}
```

```java
public class GenericQueue<E> {
  private java.util.LinkedList<E> list = new java.util.LinkedList<E>();

  public void enqueue(E e) {
    list.addLast(e);
  }

  public E dequeue() {
    return list.removeFirst();
  }

  public int getSize() {
    return list.size();
  }

  @Override
  public String toString() {
    return "Queue: " + list.toString();
  }

}
```

Example: Using Stacks and Queues

- Write a program that creates a stack and a queue

```
public class TestStackQueue {
  public static void main(String[] args) {
    // Create a stack
    GenericStack<String> stack = new GenericStack<>();

    // Add elements to the stack
    stack.push("Tom"); // Push it to the stack
    System.out.println("(1) " + stack);

    stack.push("Susan"); // Push it to the the stack
    System.out.println("(2) " + stack);

    stack.push("Kim"); // Push it to the stack
    stack.push("Michael"); // Push it to the stack
    System.out.println("(3) " + stack);

    // Remove elements from the stack
    System.out.println("(4) " + stack.pop());
    System.out.println("(5) " + stack.pop());
    System.out.println("(6) " + stack);
```

```
(1) stack: [Tom]
(2) stack: [Tom, Susan]
(3) stack: [Tom, Susan, Kim,
    Michael]
(4) Michael
(5) Kim
(6) stack: [Tom, Susan]
```

```java
    // Create a queue
    GenericQueue<String> queue = new GenericQueue<>();

    // Add elements to the queue
    queue.enqueue("Tom"); // Add it to the queue
    System.out.println("(7) " + queue);

    queue.enqueue("Susan"); // Add it to the queue
    System.out.println("(8) " + queue);

    queue.enqueue("Kim"); // Add it to the queue
    queue.enqueue("Michael"); // Add it to the queue
    System.out.println("(9) " + queue);

    // Remove elements from the queue
    System.out.println("(10) " + queue.dequeue());
    System.out.println("(11) " + queue.dequeue());
    System.out.println("(12) " + queue);
  }
}
```

```
(7) Queue: [Tom]
(8) Queue: [Tom, Susan]
(9) Queue: [Tom, Susan, Kim, Michael]
(10) Tom
(11) Susan
(12) Queue: [Kim, Michael]
```

Priority Queue

- A regular queue is a **first-in and first-out data** (***FIFO***) structure:
  - Elements are appended to the end of the queue and are removed from the beginning of the queue
- In a priority queue, elements are assigned with priorities
  - When accessing elements, the element with the highest priority is removed first
  - A priority queue has a largest-in, first-out behavior
  - For example, the emergency room in a hospital assigns patients with priority numbers; the patient with the highest priority is treated first

MyPriorityQueue
<E extends Comparable<E>>

```
-heap: Heap<E>
```

```
+enqueue(element: E): void
+dequeue(): E
+getSize(): int
```

Adds an element to this queue.
Removes an element from this queue.
Returns the number of elements in this queue.

```java
public class MyPriorityQueue<E extends Comparable<E>> {
  private Heap<E> heap = new Heap<E>();

  public void enqueue(E newObject) {
    heap.add(newObject);
  }

  public E dequeue() {
    return heap.remove();
  }

  public int getSize() {
    return heap.getSize();
  }
}
```

```java
public class TestPriorityQueue {

  public static void main(String[] args) {
    Patient patient1 = new Patient("John", 2);
    Patient patient2 = new Patient("Jim", 1);
    Patient patient3 = new Patient("Tim", 5);
    Patient patient4 = new Patient("Cindy", 7);

    MyPriorityQueue<Patient> priorityQueue = new MyPriorityQueue<>();

    priorityQueue.enqueue(patient1);
    priorityQueue.enqueue(patient2);
    priorityQueue.enqueue(patient3);
    priorityQueue.enqueue(patient4);

    while (priorityQueue.getSize() > 0)
      System.out.print(priorityQueue.dequeue() + " ");

// Cindy(priority:7) Tim(priority:5) John(priority:2) Jim(priority:1)

  }
```

```
  static class Patient implements Comparable<Patient> {
    private String name;
    private int priority;

    public Patient(String name, int priority) {
      this.name = name;
      this.priority = priority;
    }

    @Override
    public String toString() {
      return name + "(priority:" + priority + ")";
    }

    public int compareTo(Patient o) {
      return this.priority - o.priority;
    }
  }
}
```