BASIC DATA STRUCTURES

CS062

DATA STRUCTURES AND ADVANCED PROGRAMMING

8: Doubly Linked Lists

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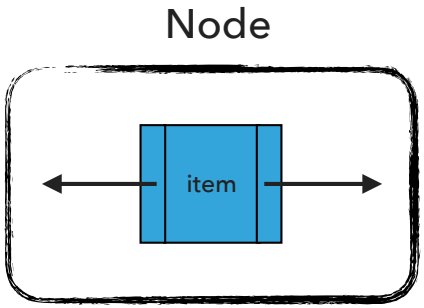
Lecture 8: Doubly Linked Lists

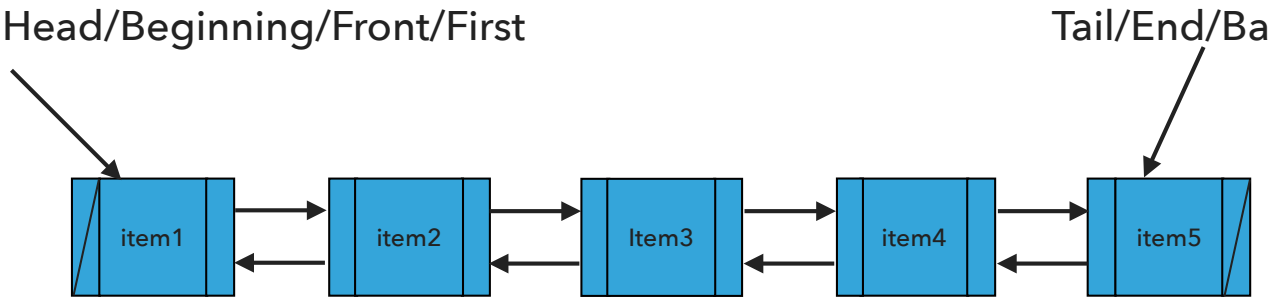
- Doubly Linked Lists
- Java Collections

Some slides adopted from Algorithms 4th Edition and Oracle tutorials

Recursive Definition of Doubly Linked Lists

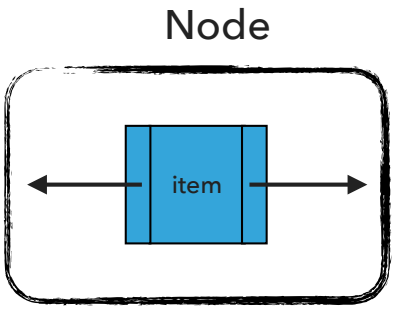
- A doubly linked list is either empty (null) or a node having a reference to a doubly linked list.
- Node: is a data type that holds any kind of data and two references to the previous and next node.





Node

```
private class Node {
    Item item;
    Node next;
    Node prev;
  }
```



Standard Operations

- `DoublyLinkedList()`: Constructs an empty doubly linked list.
- `isEmpty()`:Returns true if the doubly linked list does not contain any item.
- `size()`: Returns the number of items in the doubly linked list.
- `get(int index)`: Returns the item at the specified index.
- `addFirst(Item item)`: Inserts the specified item at the head of the doubly linked list.
- `addLast(Item item)`: Inserts the specified item at the tail of the doubly linked list.
- `add(int index, Item item)`: Inserts the specified item at the specified index.
- `Item removeFirst()`: Retrieves and removes the head of the doubly linked list.
- `Item removeLast()`: Retrieves and removes the tail of the doubly linked list.
- `Item remove(int index)`: Retrieves and removes the item at the specified index.

`DoublyLinkedList()`: Constructs an empty DLL

head

tail

n

What should happen?

```
DoublyLinkedList<String> dll = new DoublyLinkedList<String>();
```

`DoublyLinkedList()`: Constructs an empty DLL

```
DoublyLinkedList<String> dll = new DoublyLinkedList<String>();
```

head = null

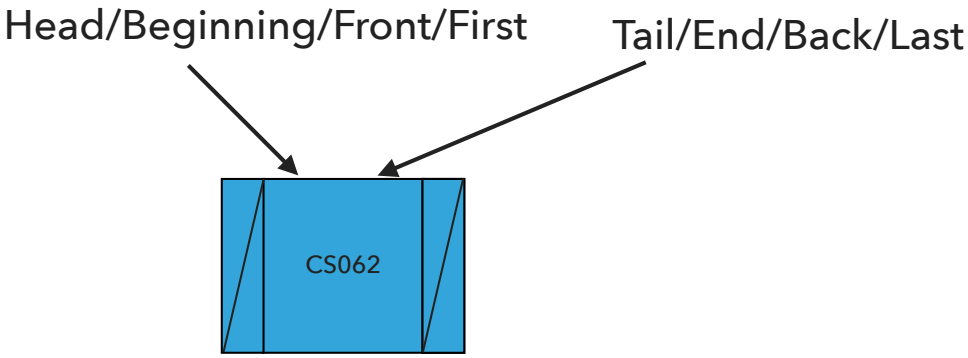
tail = null

n = 0

What should happen?

```
dll.addFirst("CS062");
```

`addFirst(Item item)`: Inserts the specified item at the head of the doubly linked list

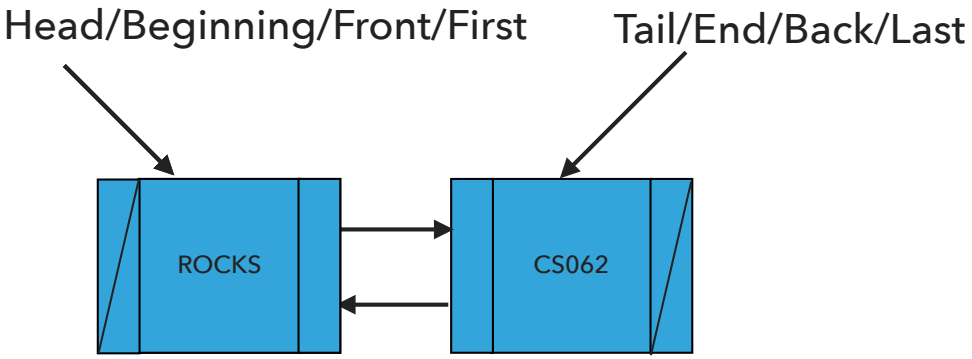



```
dll.addFirst("CS062")

n=1
```

What should happen?

```
dll.addFirst("ROCKS");
```

`addFirst(Item item)`: Inserts the specified item at the head of the doubly linked list

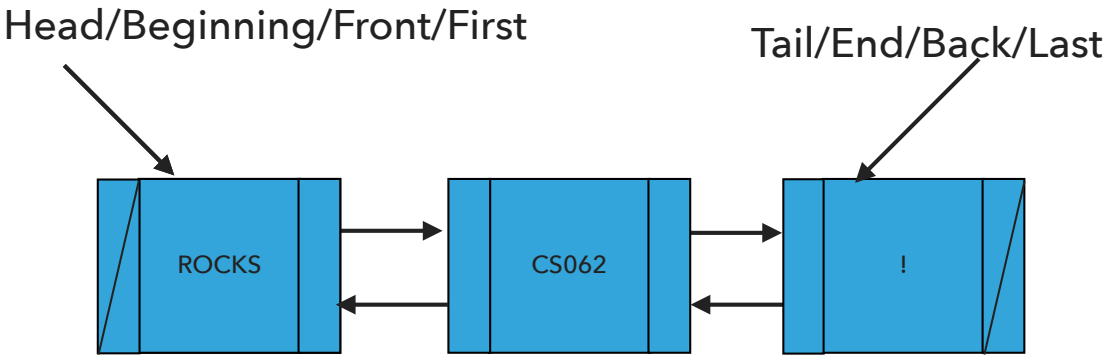



```
dll.addFirst("ROCKS")

n=2
```

What should happen?

```
dll.addLast("!");
```

`addLast(Item item)`: Inserts the specified item at the tail of the doubly linked list

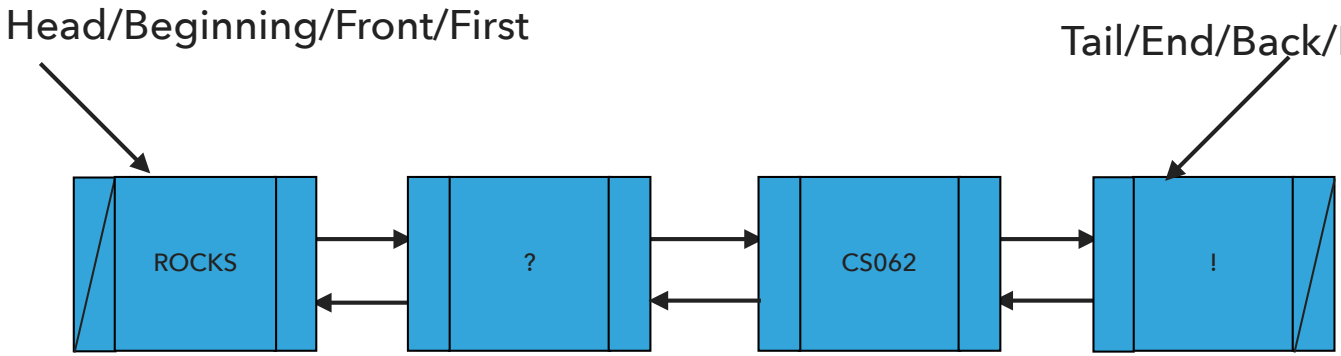



```
dll.addLast("!")

n=3
```

What should happen?

```
dll.add(1,"?");
```

`add(int index, Item item)`: Adds item at the specified index



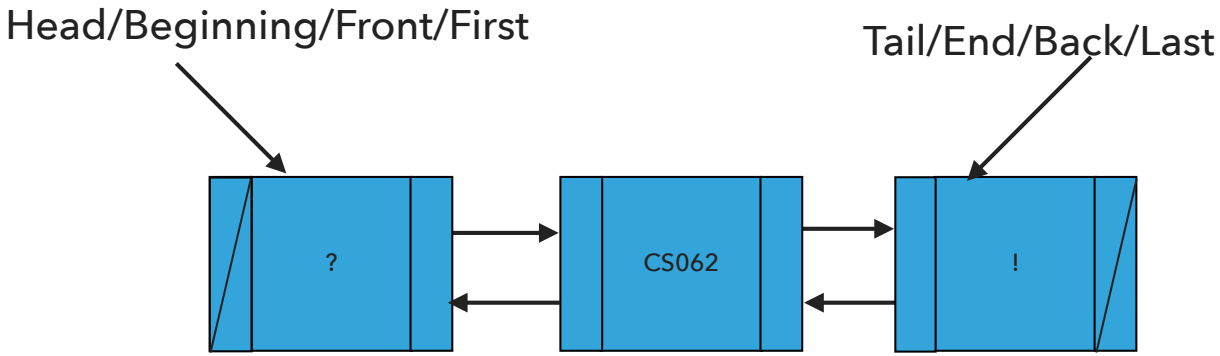

```
dll.add(1,“?”)
```

n=4

What should happen?

```
dll.removeFirst();
```

`removeFirst()`: Retrieves and removes the head of the doubly linked list



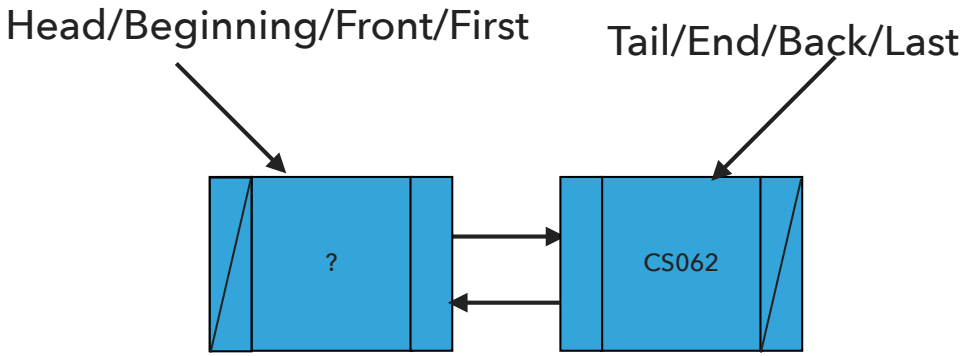

```
dll.removeFirst()
```

n=3

What should happen?

```
dll.removeLast();
```

`removeLast()`: Retrieves and removes the tail of the doubly linked list



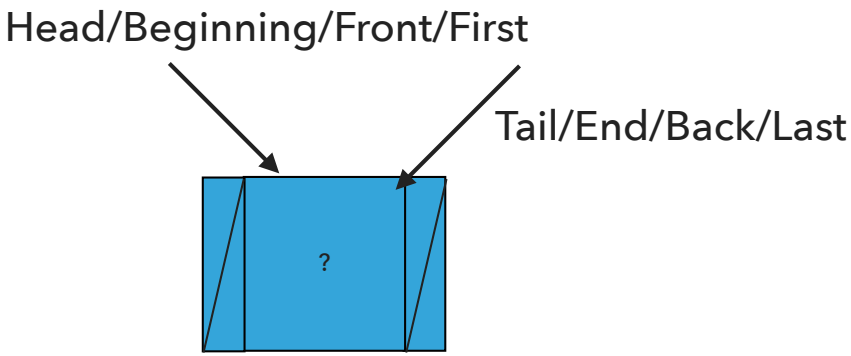

```
dll.removeLast()
```

n=2

What should happen?

```
dll.remove(1);
```

`remove(int index)`: Retrieves and removes the item at the specified index




```
dll.remove(1)
```

n=1

Our own implementation of Doubly Linked Lists

- We will follow the textbook style.
  - It does not offer a class for this so we will build our own.
- We will work with generics because we don't want to offer multiple implementations.
- We will use an inner class Node and we will keep track of how many elements we have in our doubly linked list.

Instance variables and inner class

```
public class DoublyLinkedList<Item> implements Iterable<Item> {
   private Node first; // head of the doubly linked list
   private Node last; // tail of the doubly linked list
   private int n; // number of nodes in the doubly linked list

   /**
    * This nested class defines the nodes in the doubly linked list with a value
    * and pointers to the previous and next node they are connected.
    */
   private class Node {
      Item item;
      Node next;
      Node prev;
   }
```

PRACTICE TIME: Check if is empty and how many items

```
/**
 * Returns true if the doubly linked list does not contain any item.
 *
 * @return true if the doubly linked list does not contain any item
 */
public boolean isEmpty() {

}

/**
 * Returns the number of items in the doubly linked list.
 *
 * @return the number of items in the doubly linked list
 */
public int size() {

}
```

Check if is empty and how many items

```
/**
 * Returns true if the doubly linked list does not contain any item.
 *
 * @return true if the doubly linked list does not contain any item
 */
public boolean isEmpty() {
    return size() == 0;
}

/**
 * Returns the number of items in the doubly linked list.
 *
 * @return the number of items in the doubly linked list
 */
public int size() {
    return n;
}
```

Check if index is >=0 and <n

```
/**
 * A helper method to check if an index is in range 0<=index<n
 *
 * @param index
 *            the index to check
 */
private void rangeCheck(int index) {
    if (index > n || index < 0)
        throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
}
```

PRACTICE TIME: Retrieve item from specified index

```
/**
 * Returns item at the specified index.
 *
 * @param index
 *            the index of the item to be returned
 * @return the item at specified index
 */
public Item get(int index) {
    // check whether index is valid

    // if index is 0, return item at head


     // else if index is n-1, return item at tail


    // set a temporary pointer to the head

    // search for index-th element or end of list


    // return the item stored in the node that the temporary pointer points to
}
```

Retrieve item from specified index

```
/**
 * Returns item at the specified index.
 *
 * @param index
 *            the index of the item to be returned
 * @return the item at specified index
 */
public Item get(int index) {
    // check whether index is valid
    rangeCheck(index);
    // if index is 0, return item at head
    if (index == 0)
        return first.item;
    // else if index is n-1, return item at tail
    else if (index == size() - 1)
        return last.item;
    // set a temporary pointer to the head
    Node finger = first;
    // search for index-th element or end of list
    while (index > 0) {
        finger = finger.next;
        index--;
    }
    // return the item stored in the node that the temporary pointer points to
    return finger.item;
}
```

PRACTICE TIME: Insert item at head of doubly linked list

```
/**
 * Inserts the specified item at the head of the doubly linked list.
 *
 * @param item
 *            the item to be inserted
 */
public void addFirst(Item item) {
    // Create a pointer to head

    // Make a new node and assign it to head. Fix pointers and update item



    // if first node to be added, adjust tail to it.


    // else fix previous pointer to head

    // increase number of nodes in doubly linked list.

}
```

Insert item at head of doubly linked list

```
/**
 * Inserts the specified item at the head of the doubly linked list.
 *
 * @param item
 *            the item to be inserted
 */
public void addFirst(Item item) {
    // Create a pointer to head
    Node oldfirst = first;

    // Make a new node and assign it to head. Fix pointers and update item
    first = new Node();
    first.item = item;
    first.next = oldfirst;
    first.prev = null;

    // if first node to be added, adjust tail to it.
    if (last == null)
        last = first;
    else
    // else fix previous pointer to head
        oldfirst.prev = first;
    // increase number of nodes in doubly linked list.
    n++;
}
```

PRACTICE TIME: Insert item at tail of doubly linked list

```
/**
 * Inserts the specified item at the tail of the doubly linked list.
 *
 * @param item
 *            the item to be inserted
 */
public void addLast(Item item) {
    // Create a pointer to tail

    // Make a new node and assign it to head. Fix pointers and update item



    // if first node to be added, adjust head to it.


    // else fix next pointer to tail

    // increase number of nodes in doubly linked list.

}
```

Insert item at tail of doubly linked list

```
/**
 * Inserts the specified item at the tail of the doubly linked list.
 *
 * @param item
 *            the item to be inserted
 */
public void addLast(Item item) {
    // Create a pointer to tail
    Node oldlast = last;

    // Make a new node and assign it to head. Fix pointers and update item
    last = new Node();
    last.item = item;
    last.next = null;
    last.prev = oldlast;

    // if first node to be added, adjust head to it.
    if (first == null)
        first = last;
    else
    // else fix next pointer to tail
        oldlast.next = last;
    // increase number of nodes in doubly linked list.
    n++;
}
```

PRACTICE TIME: Insert item at a specified index

```
/**
 * Inserts the specified item at the specified index.
 *
 * @param index
 *            the index to insert the item
 * @param item
 *            the item to insert
 */
public void add(int index, Item item) {
       // check whether index is valid

        // if index is 0, call addFirst


        // if index is n, call addLast


        // else
             // Make two new Node references, previous and finger. Set previous to null and finger to head

          // search for index-th position. Set previous to finger and move finger to next position


          // create new Node, update its item, and fix its pointers taking into account where finger and previous are

             // increase number of nodes
}
```

Insert item at a specified index

```
/**
 * Inserts the specified item at the specified index.
 *
 * @param index
 *            the index to insert the item
 * @param item
 *            the item to insert
 */
public void add(int index, Item item) {
      // check whether index is valid
      rangeCheck(index);
       // if index is 0, call addFirst
      if (index == 0) {
            addFirst(item);
       // if index is n, call addLast
      } else if (index == size()) {
            addLast(item);
       // else
      } else {
             // Make two new Node references, previous and finger. Set previous to null and finger to head
            Node previous = null;
            Node finger = first;
            // search for index-th position. Set previous to finger and move finger to next position
            while (index > 0) {
                  previous = finger;
                  finger = finger.next;
                  index--;
            }
            // create new Node, update its item, and fix its pointers taking into account where finger and previous are
            Node current = new Node();
            current.item = item;
            current.next = finger;
            current.prev = previous;
            previous.next = current;
            finger.prev = current;
             // increase number of nodes
            n++;
      }
}
```

Retrieve and remove head

```
/**
 * Retrieves and removes the head of the doubly linked list.
 *
 * @return the head of the doubly linked list.
 */
public Item removeFirst() {
    // Create a pointer to head

    // Move head to next

    // if least 1 nodes left

        // set previous pointer of head to null

    // else

        // remove tail by setting it to null


    // set old head's next pointer to null

    // decrease number of nodes

    // return old head's item

}
```

Retrieve and remove head

```
/**
 * Retrieves and removes the head of the doubly linked list.
 *
 * @return the head of the doubly linked list.
 */
public Item removeFirst() {
    // Create a pointer to head
    Node oldFirst = first;
    // Move head to next
    first = first.next;
    // if least 1 nodes left
    if (first != null) {
        // set previous pointer of head to null
        first.prev = null;
    // else
    } else {
        // remove tail by setting it to null
        last = null;
    }
    // set old head's next pointer to null
    oldFirst.next = null;
    // decrease number of nodes
    n--;
    // return old head's item
    return oldFirst.item;
}
```

PRACTICE TIME: Retrieve and remove tail

```
/**
 * Retrieves and removes the tail of the doubly linked list.
 *
 * @return the tail of the doubly linked list.
 */
public Item removeLast() {
    // Create a pointer to tail

    // Move tail to previous

    // if removed the last node

        // set head to null

    // else

        // set new tail's next to null
    }
    // decrease number of nodes

    // return old tail's item

}
```

Retrieve and remove tail

```
/**
 * Retrieves and removes the tail of the doubly linked list.
 *
 * @return the tail of the doubly linked list.
 */
public Item removeLast() {
    // Create a pointer to tail
    Node temp = last;
    // Move tail to previous
    last = last.prev;
    // if removed the last node
    if (last == null) {
        // set head to null
        first = null;
    // else
    } else {
        // set new tail's next to null
        last.next = null;
    }
    // decrease number of nodes
    n--;
    // return old tail's item
    return temp.item;
}
```

PRACTICE TIME: Retrieve and remove element from a specific index

```
/**
 * Retrieves and removes the item at the specified index.
 *
 * @param index
 *            the index of the item to be removed
 * @return the item previously at the specified index
 */
public Item remove(int index) {
      // check whether index is valid

     // if index is 0

            // return removeFirst

     // else if index is n-1

            // return removeLast

     // else
            // Make two new Node references, previous and finger. Set previous to null and finger to head

            // search for index-th position. Set previous to finger and move finger to next position


            // update pointers for previous and finger


            // decrease number of nodes

            // return the item that finger points to

      }

}
```

Retrieve and remove element from a specific index

```
/**
 * Retrieves and removes the item at the specified index.
 *
 * @param index
 *            the index of the item to be removed
 * @return the item previously at the specified index
 */
public Item remove(int index) {
      // check whether index is valid
       rangeCheck(index);
      // if index is 0
       if (index == 0) {
             // return removeFirst
             return removeFirst();
      // else if index is n-1
       } else if (index == size() - 1) {
             // return removeLast
             return removeLast();
      // else
       } else {
             // Make two new Node references, previous and finger. Set previous to null and finger to head
             Node previous = null;
             Node finger = first;
             // search for index-th position. Set previous to finger and move finger to next position
             while (index > 0) {
                   previous = finger;
                   finger = finger.next;
                   index--;
             }
             // update pointers for previous and finger
             previous.next = finger.next;
             finger.next.prev = previous;
             // decrease number of nodes
             n--;
             // return the item that finger points to
             return finger.item;
       }

}
```

addFirst() in doubly linked lists is $O(1)$ for worst case

```
public void addFirst(Item item) {
       // Save the old node
       Node oldfirst = first;

       // Make a new node and assign it to head. Fix pointers.
       first = new Node();
       first.item = item;
       first.next = oldfirst;
       first.prev = null;

       // if first node to be added, adjust tail to it.
       if (last == null)
          last = first;
       else
          oldfirst.prev = first;

       n++; // increase number of nodes in doubly linked list.
   }
```

addLast() in doubly linked lists is $O(1)$ for worst case

```
public void addLast(Item item) {
       // Save the old node
       Node oldlast = last;

       // Make a new node and assign it to tail. Fix pointers.
       last = new Node();
       last.item = item;
       last.next = null;
       last.prev = oldlast;

       // if first node to be added, adjust head to it.
       if (first == null)
          first = last;
       else
          oldlast.next = last;

       n++;
   }
```

`add(int index, Item item)` in doubly linked lists is $O(n)$ for worst case

```
public void add(int index, Item item) {
          rangeCheck(index);

          if (index == 0) {
               addFirst(item);
          } else if (index == size()) {
               addLast(item);
          } else {

               Node previous = null;
               Node finger = first;
               // search for index-th position
               while (index > 0) {
                    previous = finger;
                    finger = finger.next;
                    index--;
               }
               // create new value to insert in correct position
               Node current = new Node();
               current.item = item;
               current.next = finger;
               current.prev = previous;
               previous.next = current;
               finger.prev = current;

               n++;
          }
     }
```

`removeFirst()` in doubly linked lists is $O(1)$ for worst case

```
public Item removeFirst() {
       Node oldFirst = first;
       // Fix pointers.
       first = first.next;
       // at least 1 nodes left.
       if (first != null) {
          first.prev = null;
       } else {
          last = null; // remove final node.
       }
       oldFirst.next = null;

       n--;

       return oldFirst.item;
   }
```

`removeLast()` in doubly linked lists is $O(1)$ for worst case

```
public Item removeLast() {

    Node temp = last;
    last = last.prev;

    // if there was only one node in the doubly linked list.
    if (last == null) {
        first = null;
    } else {
        last.next = null;
    }
    n--;
    return temp.item;
}
```

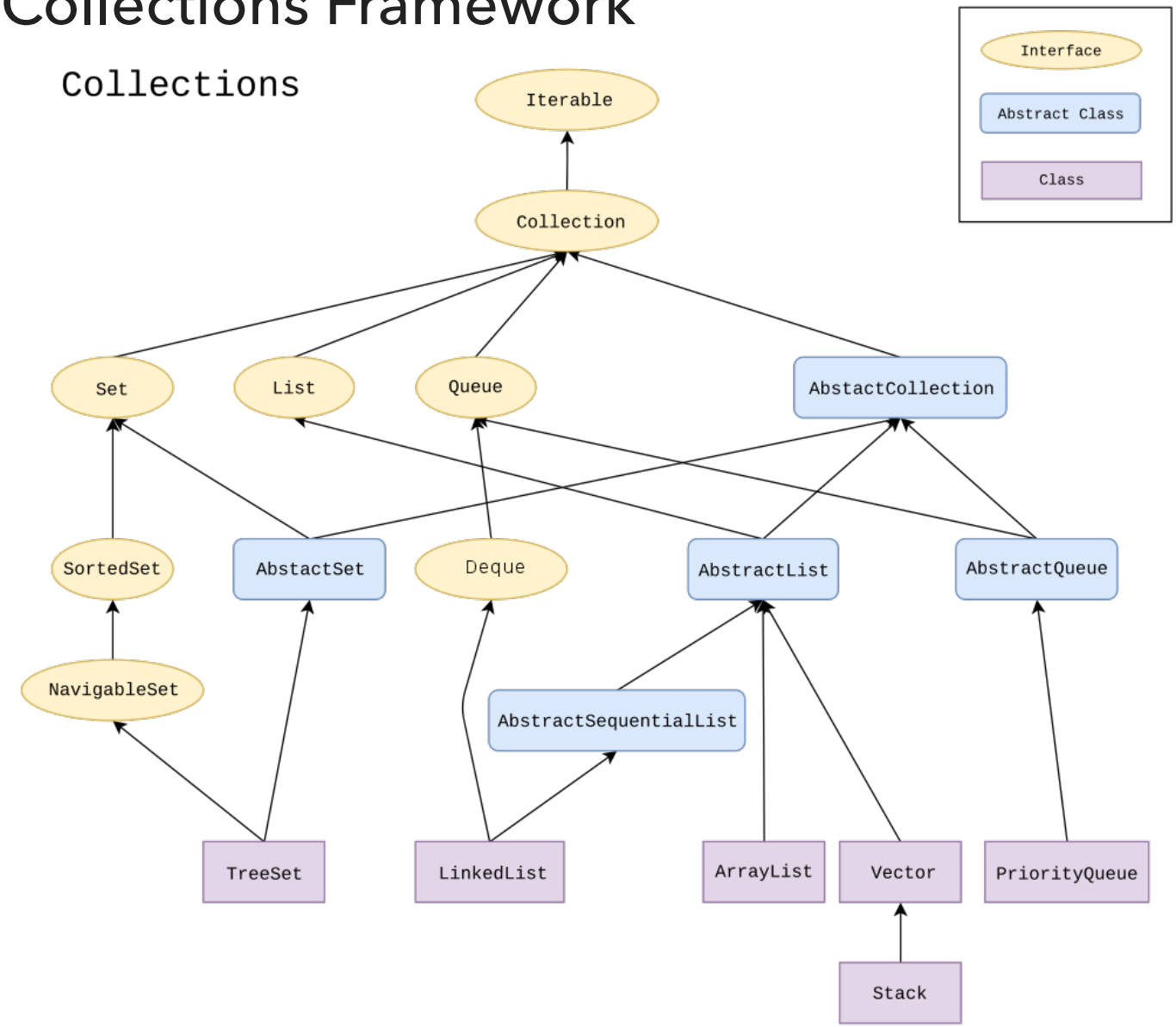
`remove(int index)` in doubly linked lists is $O(n)$ for worst case

```
public Item remove(int index) {
     rangeCheck(index);

     if (index == 0) {
          return removeFirst();
     } else if (index == size() - 1) {
          return removeLast();
     } else {
          Node previous = null;
          Node finger = first;
          // search for value indexed, keep track of previous
          while (index > 0) {
               previous = finger;
               finger = finger.next;
               index--;
          }
          previous.next = finger.next;
          finger.next.prev = previous;

          n--;
          // finger's value is old value, return it
          return finger.item;
     }

}
```

Lecture 8: Doubly Linked Lists

- Doubly Linked Lists
- Java Collections

The Java Collections Framework



https://en.wikipedia.org/wiki/Java_collections_framework

`LinkedList` in Java Collections

- Doubly linked list implementation of the `List` and `Deque` (stay tuned) interfaces.

```
java.util.LinkedList;
```

```
public class LinkedList<E> extends
AbstractSequentialList<E> implements List<E>, Deque<E>
```

https://docs.oracle.com/javase/7/docs/api/java/util/LinkedList.html

Lecture 8: Doubly Linked Lists

- Doubly Linked Lists
- Java Collections

Readings:

- Oracle's guides:
  - Collections: https://docs.oracle.com/javase/tutorial/collections/intro/index.html
  - Linked Lists: https://docs.oracle.com/javase/7/docs/api/java/util/LinkedList.html
- Textbook:
  - Chapter 1.3 (Page 142–146)
- Textbook Website:
  - Linked Lists: https://algs4.cs.princeton.edu/13stacks/

Practice Problems:

- 1.3.18–1.3.27 (approach them as doubly linked lists).