CS062

DATA STRUCTURES AND ADVANCED PROGRAMMING

9: Singly Linked Lists

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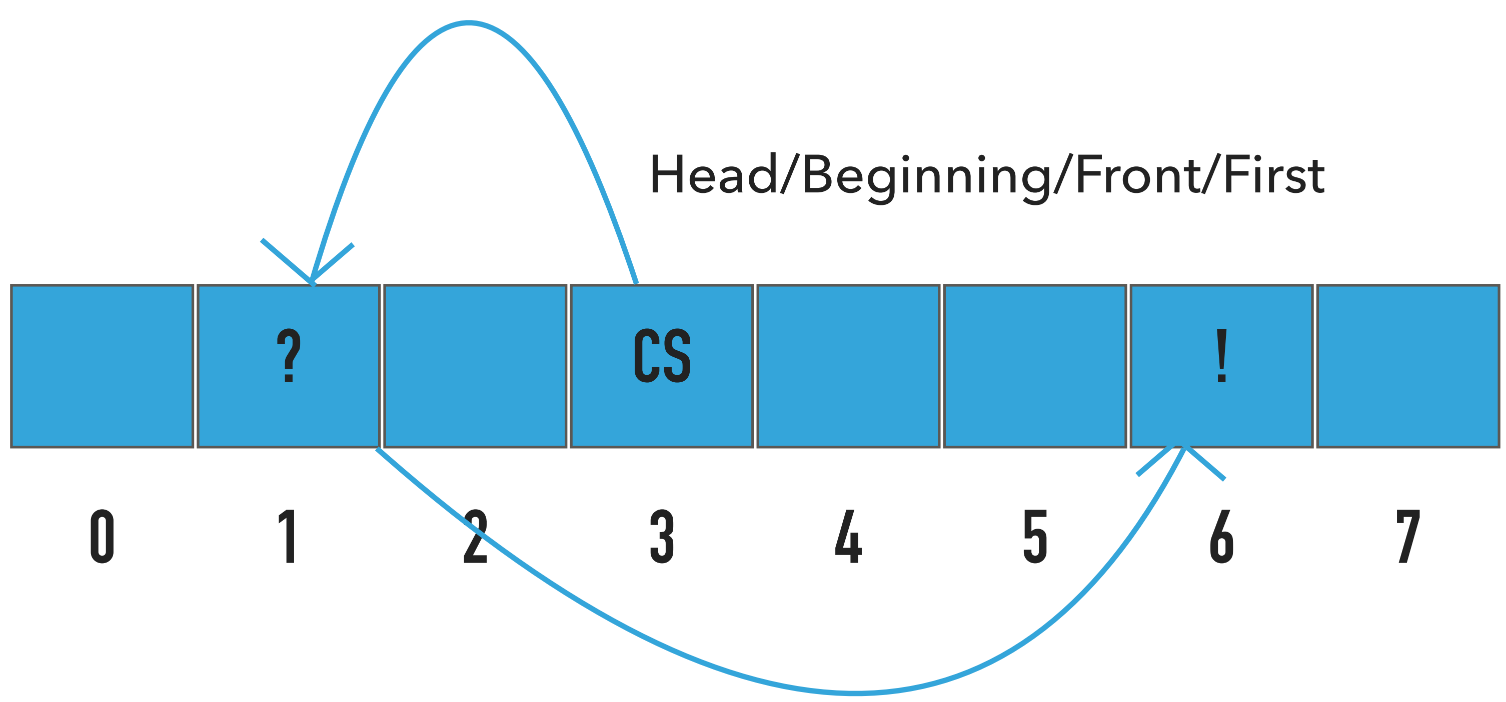
Lecture 9: Singly Linked Lists

- Singly Linked Lists

Some slides adopted from Algorithms 4th Edition and Oracle tutorials

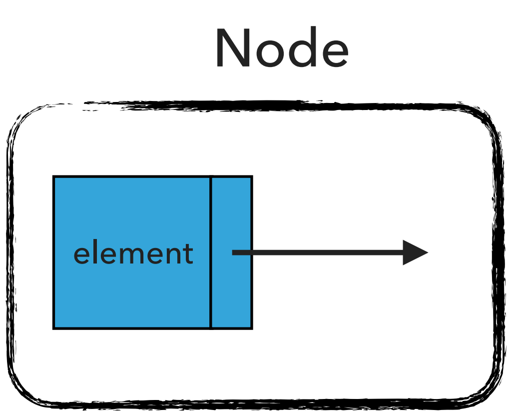
Singly Linked Lists

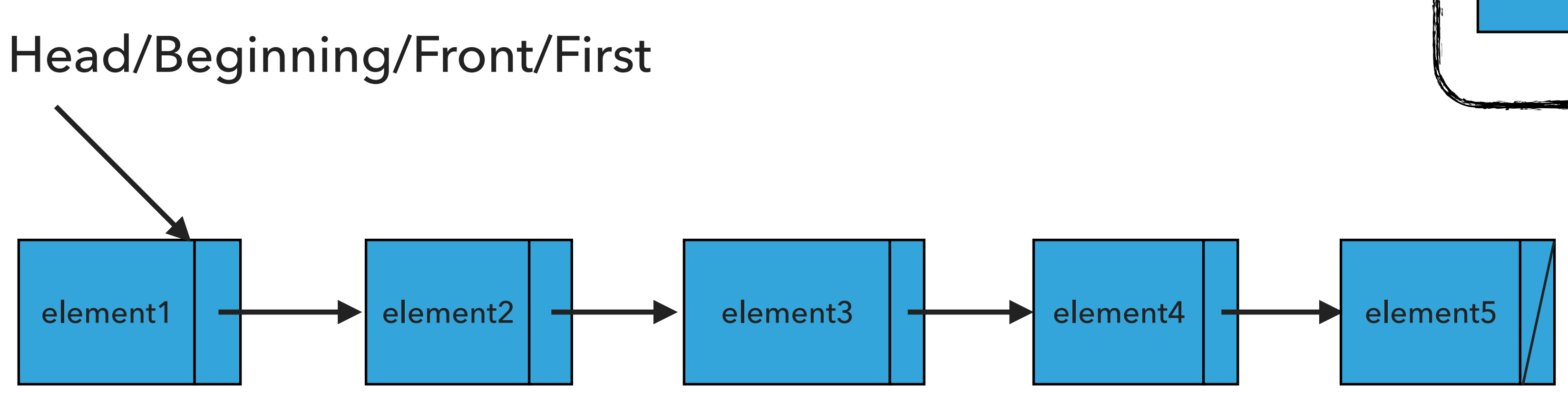
- Dynamic linear data structures.
- In contrast to sequential data structures, linked data structures use pointers/links/references from one object to another.



Recursive Definition of Singly Linked Lists

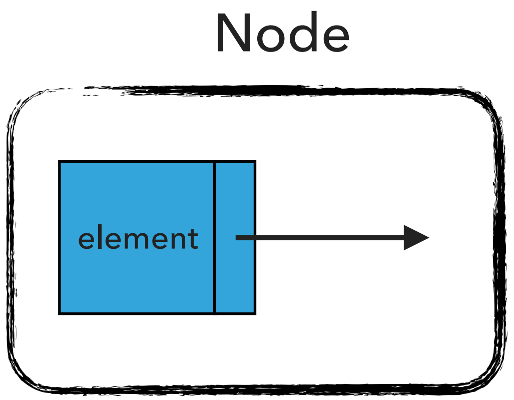
- A singly linked list is either empty (null) or a node having a reference to a singly linked list.
- Node: is a data type that holds any kind of data and a reference to a node.





Node

```
private class Node {
    E element;
    Node next;
  }
```



Reminder: Interface List

```
public interface List <E> {
    void add(E element);
    void add(int index, E element);
    void clear();
    E get(int index);
    boolean isEmpty();
    E remove();
    E remove(int index);
    E set(int index, E element);
    int size();
}
```

Standard Operations

- `SinglyLinkedList()`: Constructs an empty singly linked list.
- `isEmpty()`:Returns true if the singly linked list does not contain any element.
- `size()`: Returns the number of elements in the singly linked list.
- `E get(int index)`: Returns the element at the specified index.
- `add(E element)`: Inserts the specified element at the head of the singly linked list.
- `add(int index, E element)`: Inserts the specified element at the specified index.
- E `set(int index, E element)`: Replaces the specified element at the specified index and returns the old element
- `E remove()`: Removes and returns the head of the singly linked list.
- `E remove(int index)`: Removes and returns the element at the specified index.
- `clear()`: Removes all elements.

`SinglyLinkedList()`: Constructs an empty SLL

head = ?

size = ?

What should happen?

```
SinglyLinkedList<String> sll = new SinglyLinkedList<String>();
```

`SinglyLinkedList()`: Constructs an empty SLL

```
SinglyLinkedList<String> sll = new SinglyLinkedList<String>();
```

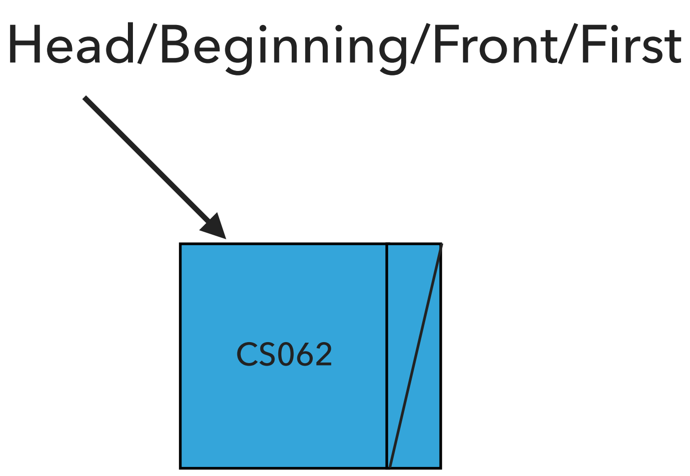
head = null

size = 0

What should happen?

```
sll.add("CS062");
```

`add(E element)`: Inserts the specified element at the head of the singly linked list



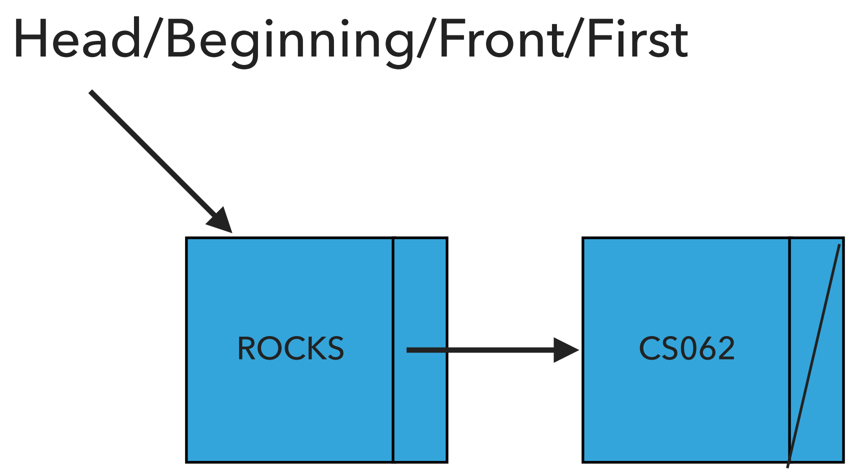

```
sll.add("CS062")

size=1
```

What should happen?

```
sll.add("ROCKS");
```

`add(E element)`: Inserts the specified element at the head of the singly linked list



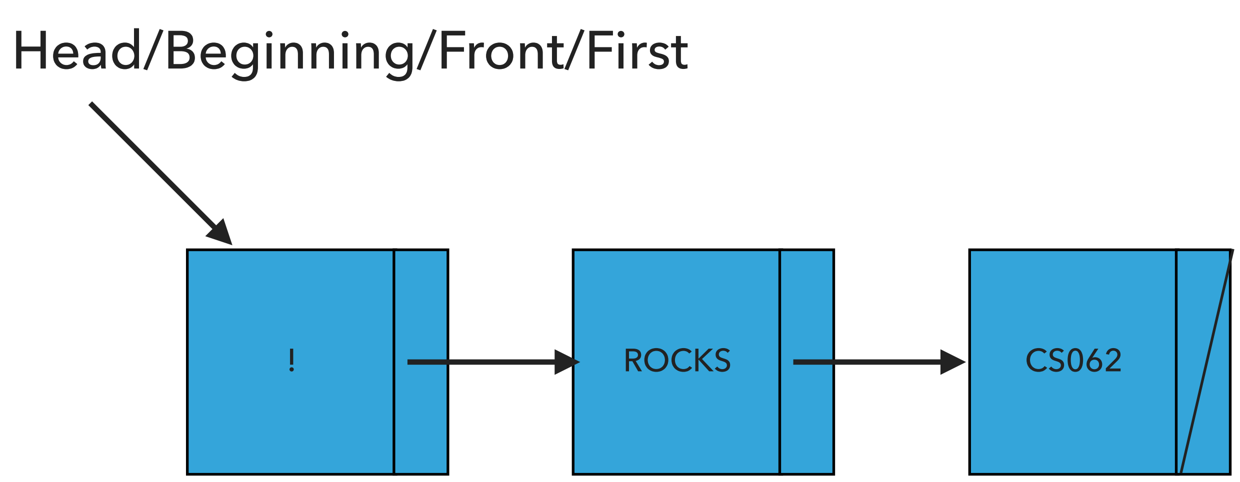

```
sll.add("ROCKS")

size=2
```

What should happen?

```
sll.add("!");
```

`add(E element)`: Inserts the specified element at the head of the singly linked list



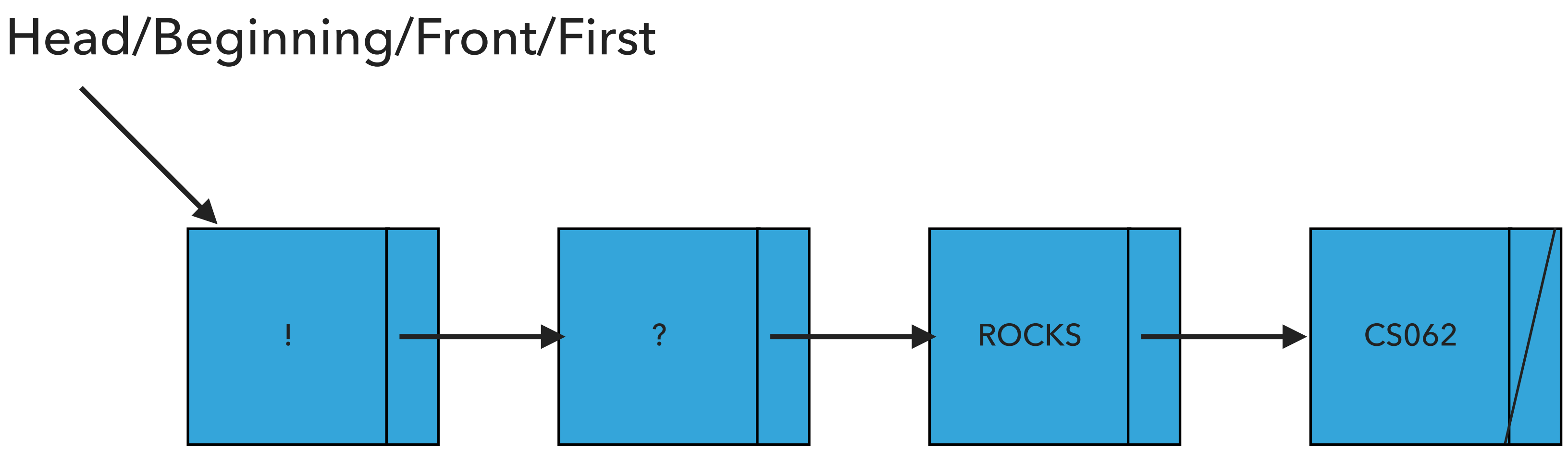

```
sll.add("!")

size=3
```

What should happen?

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

`add(int index, E element)`: Adds element at the specified index



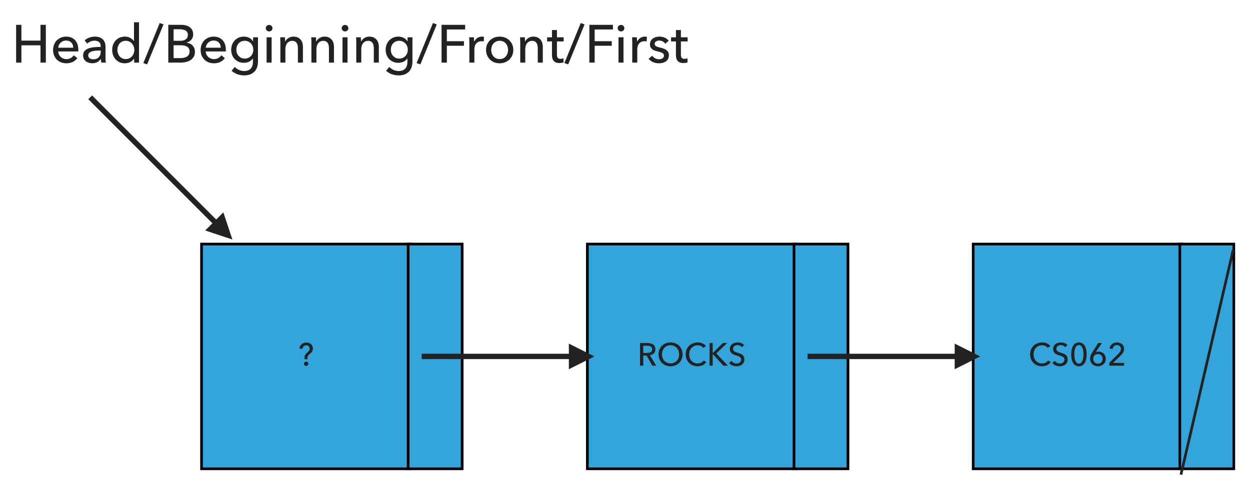
`sll.add(1,“?”)`

`size=4`

What should happen?

`sll.remove();`

`remove()`: Removes and returns the head of the singly linked list



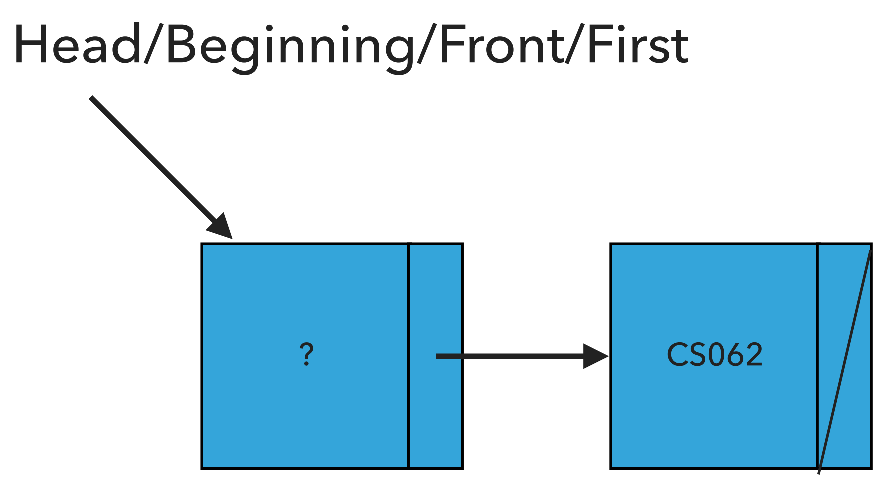

```
sll.remove()

size=3
```

What should happen?

```
sll.remove(1);
```

`remove(int index)`: Removes and returns the element at the specified index




```
sll.remove(1)

size=2
```

Our own implementation of Singly Linked Lists

- We will follow the recommended textbook style.
  - It does not offer a class for this so we will build our own.
- We will work with generics because we want singly linked lists to hold objects of an type.
- We will implement the List interface we defined in past lectures.
- We will use an inner class Node and we will keep track of how many elements we have in our singly linked list.

Instance variables and inner class

```
public class SinglyLinkedList<E> implements List<E>{
   private Node head; // head of the singly linked list
   private int size; // number of nodes in the singly linked list

   /**
    * This nested class defines the nodes in the singly linked list with a value
    * and pointer to the next node they are connected.
    */
   private class Node {
      E element;
      Node next;
   }
```

Check if is empty and how many elements

```java
/**
 * Returns true if the singly linked list does not contain any element.
 *
 * @return true if the singly linked list does not contain any element
 */
public boolean isEmpty() {
    return head == null; // return size == 0;
}

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

Retrieve element from specified index

```java
/**
 * Returns element at the specified index.
 *
 * @param index
 *            the index of the element to be returned
 * @return the element at specified index
 * @pre 0<=index<size
 */
public E get(int index) {
    // check whether index is valid
    if (index >= size || index < 0){
        throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
    }
    // set a temporary pointer to the head
    Node finger = head;
    // search for index-th element or end of list
    while (index > 0) {
        finger = finger.next;
        index--;
    }
    // return the element stored in the node that the temporary pointer points to
    return finger.element;
}
```

Insert element at head of singly linked list

```
 /**
 * Inserts the specified element at the head of the singly linked list.
 *
 * @param element
 *           the element to be inserted
 */
public void add(E element) {
    // Create a pointer to head
    Node oldHead = head;

    // Make a new node that will hold the element and assign it to head.
    head = new Node();
    head.element = element;
    // fix pointers
    head.next = oldHead;
    // increase number of nodes
    size++;
}
```

Insert element at a specified index

```java
/**
 * Inserts the specified element at the specified index.
 *
 * @param index
 *            the index to insert the node
 * @param element
 *            the element to insert
 * @pre 0<=index<=size
 */
public void add(int index, E element) {
      // check that index is within range
      if (index > size || index < 0){
          throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
      }
      // if index is 0, then call one-argument add
      if (index == 0) {
            add(element);
      // else
      } else {
            // make two pointers, previous and finger. Point previous to null and finger to head
            Node previous = null;
            Node finger = head;
            // search for index-th position by pointing previous to finger and advancing finger
            while (index > 0) {
                  previous = finger;
                  finger = finger.next;
                  index--;
            }
            // create new node to insert in correct position. Set its pointers and contents
            Node current = new Node();
            current.next = finger;
            current.element = element;
            // make previous point to newly created node.
            previous.next = current;
            // increase number of nodes
            size++;
      }
}
```

Replace element at a specified index

```
/**
 * Inserts the specified element at the specified index.
 *
 * @param index
 *           the index of the element to replace
 * @param element
 *           the element to be stored at the specific index
 * @return the old element that was replaced
 * @pre 0<=index<size
 */
public E set(int index, E element) {
       // check that index is within range
      if (index >= size || index < 0){
           throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
       }

       Node finger = head;
       // search for index-th position by pointing previous to finger and advancing finger
       while (index > 0) {
            finger = finger.next;
            index--;
        }
        // reference old element
        E old = finger.element;
        // update element at finger
        finger.element = element;
        // return old element
        return old;
    }
}
```

Retrieve and remove head

```
/**
 * Removes and returns the head of the singly linked list.
 *
 * @return the head of the singly linked list.
 */
public E remove() {
    // Make a temporary pointer to head
    Node temp = head;
    // Move head one to the right
    head = head.next;
    // Decrease number of nodes
    size--;
    // Return element held in the temporary pointer
    return temp.element;
}
```

Retrieve and remove element from a specific index

```
/**
 * Removes and returns the element at the specified index.
 *
 * @param index
 *            the index of the element to be removed
 * @return the element previously at the specified index
 * @pre 0<=index<size
 */
public E remove(int index) {
      // check that index is within range
     if (index >= size || index < 0){
              throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
      }
      // if index is 0, then call remove
     if (index == 0) {
          return remove();
      // else
     } else {
      // make two pointers, previous and finger. Point previous to null and finger to head
          Node previous = null;
          Node finger = head;
          // search for index-th position by pointing previous to finger and advancing finger
          while (index > 0) {
               previous = finger;
               finger = finger.next;
               index--;
          }
          // make previous point to finger's next
          previous.next = finger.next;
          // reduce number of elements
          size--;
          // return finger's element
          return finger.element;
     }

}
```

Clear the singly linked list of all elements

```
/**
 * Clears the singly linked list of all elements.
 *
 */
public void clear(
        head = null;
        size = 0;

}
```

add() in singly linked lists is $O(1)$ for worst case

```
public void add(E element) {
    // Save the old node
    Node oldfirst = head;

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

    size++; // increase number of nodes in singly linked list.
}
```

get() in singly linked lists is $O(n)$ for worst case

```
public E get(int index) {
    if (index >= size || index < 0){
        throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
    }

    Node finger = head;
    // search for index-th element or end of list
    while (index > 0) {
        finger = finger.next;
        index--;
    }
    return finger.element;
}
```

`add(int index, E element)` in singly linked lists is $O(n)$ for worst case

```
public void add(int index, E element) {
         if (index > size || index < 0){
                throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
         }
        if (index == 0) {
            add(element);
        } else {

            Node previous = null;
            Node finger = head;
            // 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.next = finger;
            current.element = element;
            // make previous value point to new value.
            previous.next = current;

            size++;
        }
    }
```

`set(int index, E element)` in singly linked lists is $O(n)$ for worst case

```
/**
 * Inserts the specified element at the specified index.
 *
 * @param index
 *            the index of the element to replace
 * @param element
 *            the element to be stored at the specific index
 * @return the old element that was replaced
 * @pre 0<=index<size
 */
public E set(int index, E element) {
       // check that index is within range
      if (index >= size || index < 0){
           throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
       }

       Node finger = head;
       // search for index-th position by pointing previous to finger and advancing finger
       while (index > 0) {
            finger = finger.next;
            index--;
        }
        // reference old element
        E old = finger.element;
        // update element at finger
        finger.element = element;
        // return old element
        return old;
    }
}
```

remove() in singly linked lists is $O(1)$ for worst case

```
public E remove() {
    Node temp = head;
    // Fix pointers.
    head = first.next;

    size--;

    return temp.element;
}
```

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

```
public E remove(int index) {
     if (index >= size || index < 0){
           throw new IndexOutOfBoundsException("Index " + index + " out of bounds");
      }

    if (index == 0) {
        return remove();
    } else {
        Node previous = null;
        Node finger = head;
        // search for value indexed, keep track of previous
        while (index > 0) {
            previous = finger;
            finger = finger.next;
            index--;
        }
        previous.next = finger.next;

        size--;
        // finger's value is old value, return it
        return finger.element;
    }

}
```

`clear()` in singly linked lists is $O(1)$ for worst case

```
/**
 * Clears the singly linked list of all elements.
 *
 */
public void clear(
        head = null;
        size = 0;

}
```

Lecture 9: Singly Linked Lists

- Singly Linked Lists

Readings:

- Recommended Textbook:
  - Chapter 1.3 (Page 142–146)
- Recommended Textbook Website:
  - Linked Lists: https://algs4.cs.princeton.edu/13stacks/

Code

- Lecture 9 code

Practice Problems:

- 1.3.18–1.3.27