Implementing Linked Lists (pt. 1)

Based on slides by Prof. Burton Ma

Recursive Objects

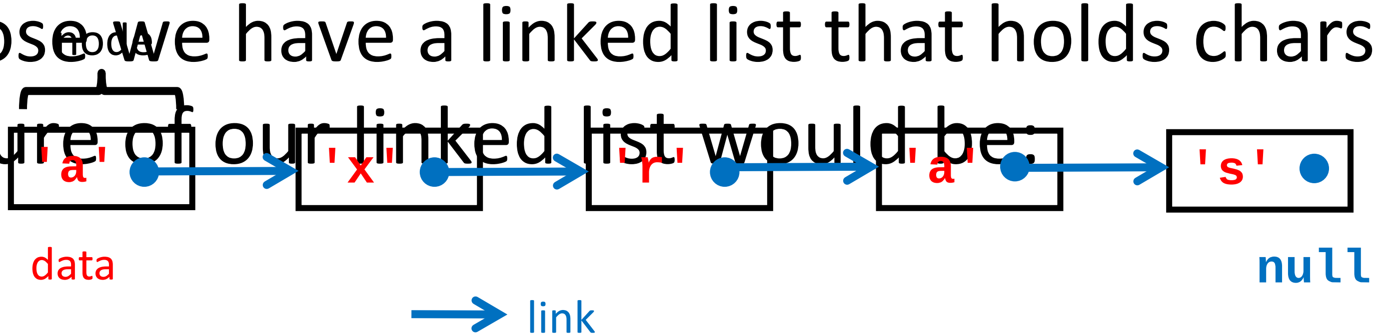
- An object that holds a reference to its own type is a recursive object
  - Linked lists and trees are classic examples in computer science of objects that can be implemented recursively

Data Structures

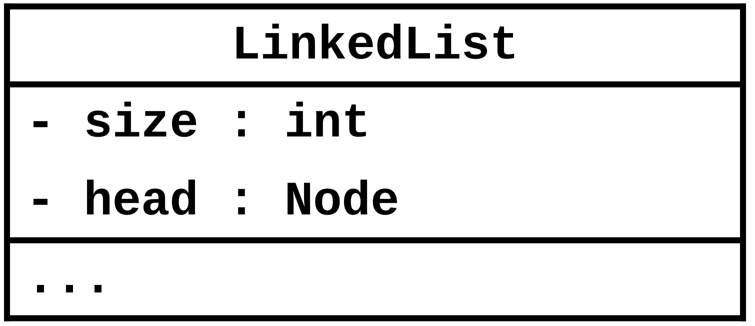
- Data structures (and algorithms) are one of the foundational elements of computer science
- A data structure is a way to organize and store data so that it can be used efficiently
  - List – sequence of elements
  - Set – a group of unique elements
  - Map – access elements using a key
  - many more...

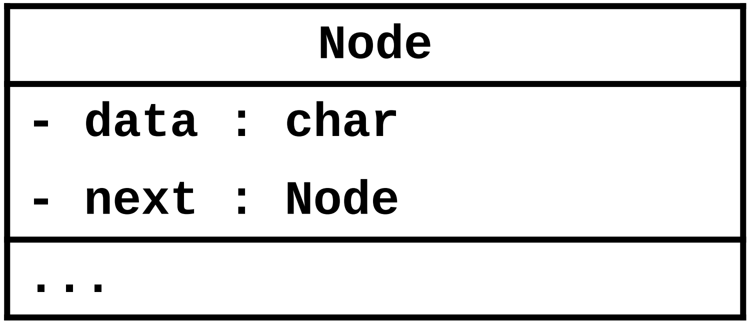
Linked Lists

- A data structure made up of a sequence of nodes
- Each node has
  - Some data
  - A field that contains a reference (a *link*) to the next node in the sequence
- Suppose we have a linked list that holds chars; a picture of our linked list would be:



UML Class Diagram





Node

- Nodes are implementation details that the client does not need to know about
  - Can be private inner classes

```
public class LinkedList {

  private static class Node {
    private char data;
    private Node next;

    public Node(char c) {
      this.data = c;
      this.next = null;
    }
  }

 // ...
}
```

LinkedList constructor

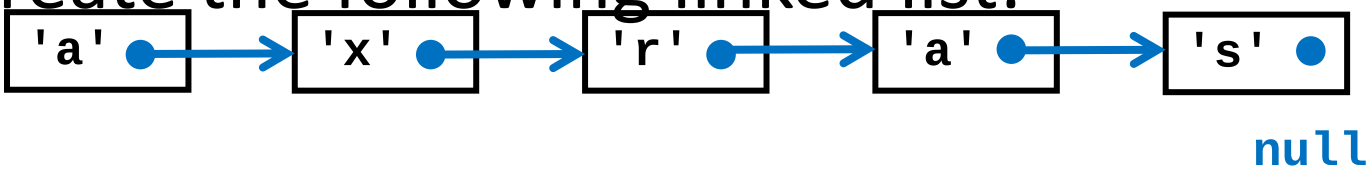
```
/**
 * Create a linked list of size 0.
 *
 */
public LinkedList() {
  this.size = 0;
  this.head = null;
}
```

Node constructor

```
/**
 * Create a node with the given character.
 *
 */
public Node(char c) {
  this.data = c;
  this.next = null;
}
```

Creating a Linked List

- To create the following linked list:




```
LinkedList t = new LinkedList();
t.add(‘a’);
t.add(‘x’);
t.add(‘r’);
t.add(‘a’);
t.add(‘s’);
```

Add to end of list

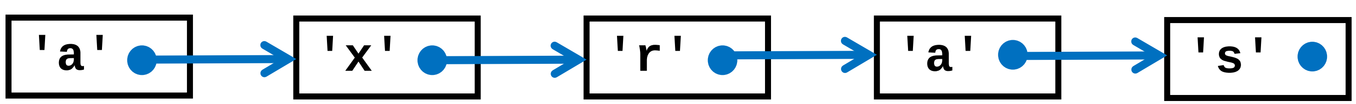
- Methods of recursive objects can often be implemented with a recursive algorithm
  - Notice the word "can"; the recursive implementation is not necessarily the most efficient implementation
- Adding to the end of the list can be done recursively
  - Base case: at the end of the list
    - I.e., **`next`** is **`null`**
    - Create new node and append it to this link
  - Recursive case: current link is not the last link
    - Add to the end of **`next`**

```java
/**
 * Adds the given character to the end of the list.
 *
 * @param c The character to add
 */
public void add(char c) {
  if (this.size == 0) {
    this.head = new Node(c);
  }
  else {
    LinkedList.add(c, this.head);
  }
  this.size++;
}
```

```java
/**
 * Adds the given character to the end of the list.
 *
 * @param c The character to add
 * @param node The node at the head of the current sublist
 */
private static void add(char c, Node node) {
  if (node.next == null) {
    node.next = new Node(c);
  }
  else {
    LinkedList.add(c, node.next);
  }
}
```

Getting an Element in the List

- A client may wish to retrieve the *i* th element from a list
  - The ability to access arbitrary elements of a sequence in the same amount of time is called *random access*
  - Arrays support random access; linked lists do not
- To access the *i* th element in a linked list we need to sequentially follow the first (*i* - 1) links



`t.get(3)` **link 0** **link 1** **link 2**

  - Takes $O(n)$ time versus $O(1)$ for arrays

Getting an Element in the List

- Validation?
- Getting the *i* th element can be done recursively
  - Base case: **`index == 0`**
    - Return the value held by the current link
  - Recursive case: current link is not the last link
    - Get the element at **`index – 1`** starting from **`next`**

```
/**
 * Returns the item at the specified position
 * in the list.
 *

 * @param index index of the element to return
 * @return the element at the specified position
 * @throws IndexOutOfBoundsException if the index
 *        is out of the range
 *        {@code (index < 0 || index >= list size)}
 */
public char get(int index) {
  if (index < 0 || index >= this.size) {
    throw new IndexOutOfBoundsException("Index: " + index +
                              ", Size: " + this.size);
  }
  return LinkedList.get(index, this.head);
}
```

```
/**
 * Returns the item at the specified position
 * in the list.
 *
 * @param index index of the element to return
 * @param node The node at the head of the current sublist
 * @return the element at the specified position
 */
private static char get(int index, Node node) {
  if (index == 0) {
    return node.data;
  }
  return LinkedList.get(index - 1, node.next);
}
```

Setting an Element in the List

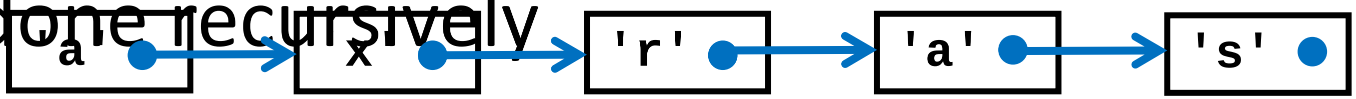
- Setting the *i* th element is almost exactly the same as getting the *i* th element

```
/**
 * Sets the element at the specified position
 * in the list.
 *
 * @param index index of the element to set
 * @param c new value of element
 * @throws IndexOutOfBoundsException if the index
 *        is out of the range
 *        {@code (index < 0 || index >= list size)}
 */
public void set(int index, char c) {
  if (index < 0 || index >= this.size) {
    throw new IndexOutOfBoundsException("Index: " + index +
                                   ", Size: " + this.size);
  }
  LinkedList.set(index, c, this.head);
}
```

```java
/**
 * Sets the element at the specified position
 * in the list.
 *
 * @param index index of the element to set
 * @param c new value of the element
 * @param node The node at the head of the current sublist
 */
private static void set(int index, char c, Node node) {
  if (index == 0) {
    node.data = c;
    return;
  }
  LinkedList.set(index - 1, c, node.next);
}
```

toString

- Finding the string representation of a list can be done recursively



  - The string is
    "[a, x, r, a, s]
  - The string is
    "[" + "a, " + toString(*the list['x', 'r', 'a', 's']***)**

toString

- Base case: `next` is `null`
  - Return the value of the link as a string + `"]"`
- Recursive case: current link is not the last link
  - Return the value of the link as a string + `", "` + the rest of the list as a string

```
public String toString() {
  if (this.size == 0) {
    return "[]";
  }
  return "[" + LinkedList.toString(this.head);
}


private static String toString(Node n) {
  if (n.next == null) {
    return n.data + "]";
  }
  String s = n.data + ", ";
  return s + LinkedList.toString(n.next);
}
```

Finding an element in the list

- Often useful to ask if a list contains a particular element
- Worst case: must visit every element of the list

  - E.g., `t.contains('z')`

Finding an element in the list

- Contains can be solved recursively
  - Base case: found the character we are looking for
    - I.e., node **`data`** is equal to the character we are searching for
      - return true
  - Base case: at the end of the list
    - I.e., node **`next`** is **`null`**
      - return false
  - Recursive case: have not found the character we are searching for and not at the end of the list
    - Search the sublist starting at **`node.next`**
      - return result

```
/**
 * Returns <code>true</code> if this list contains the specified
element.
 *
 * @param c element to search for
 * @return <code>true</code> if this list contains the
 * specified element
 */
public boolean contains(char c) {
  if (this.size == 0) {
      return false;
    }
  return LinkedList.contains(c, this.head);
}
```

```java
/**
 * Returns <code>true</code> if this list contains the specified element.
 *
 * @param c element to search for
 * @param node the node at the head of the current sublist
 * @return <code>true</code> if this list contains the
 * specified element
 */
private static boolean contains(char c, Node node) {
  if (node.data == c) {
    return true;
  }
  if (node.next == null) {
    return false;
  }
  return LinkedList.contains(c, node.next);
}
```

Finding an element in the list

- Closely related to contains is finding the index of an element in the list
- Worst case: must visit every element of the list

  - E.g., `t.indexOf('s')`

Finding an element in the list

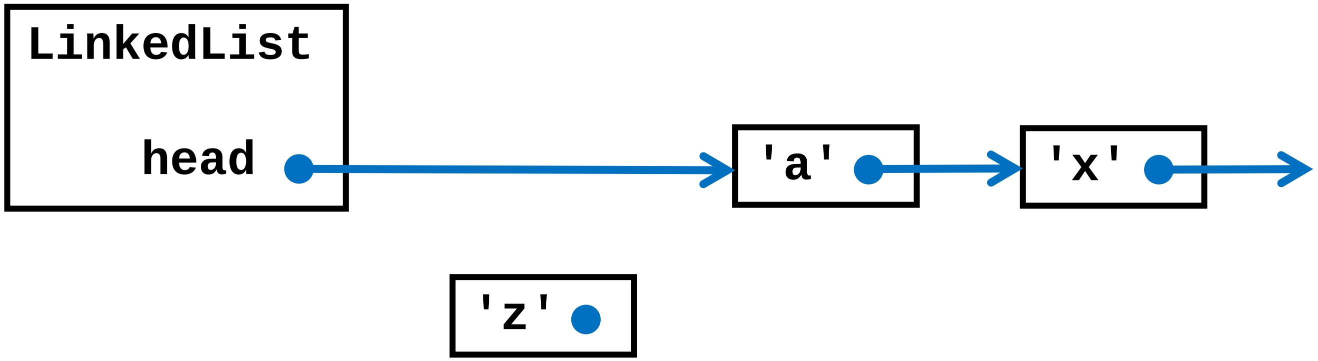
- `indexOf` can be solved recursively
  - Base case: found the character we are looking for
    - I.e., node `data` is equal to the character we are searching for
      - return 0
  - Base case: at the end of the list
    - I.e., node `next` is `null`
      - return -1
  - Recursive case: have not found the character we are searching for and not at the end of the list
    - Search the sublist starting at `node.next`
      - return 1 + result

```
/**
 * Returns the index of the first occurrence of the
 * specified element in this list, or -1 if this list
 * does not contain the element.
 *
 * @param c
 *         element to search for
 * @return the index of the first occurrence of the
 *         specified element in this list, or -1 if this
 *         list does not contain the element
 */
public int indexOf(char c) {
  if (this.size == 0) {
    return -1;
  }
  return LinkedList.indexOf(c, this.head);
}
```

```
private static int indexOf(char c, Node n) {
  if (n.data == c) {
    return 0;
  }
  if (n.next == null) {
    return -1;
  }
  int i = LinkedList.indexOf(c, n.next);
  if (i == -1) {
    return -1;
  }
  return 1 + i;
}
```

Adding to the front of the list

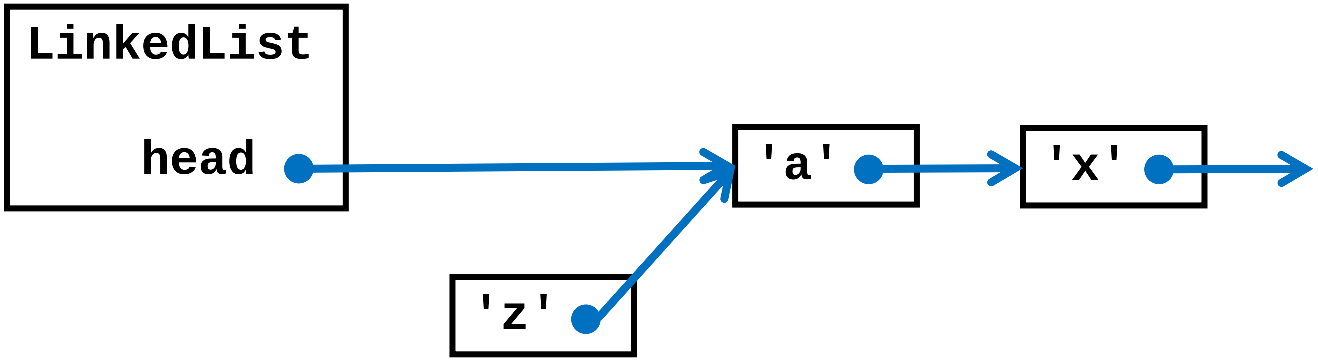
- Adding to the front of the list



- `t.addFirst('z')` or `t.add(0, 'z')`

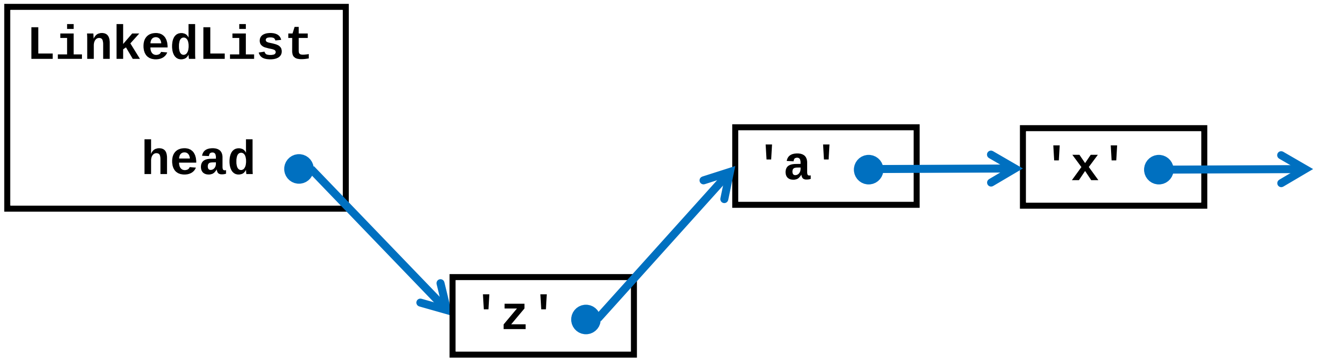
Adding to the front of the list

- Must connect to the rest of the list



Adding to the front of the list

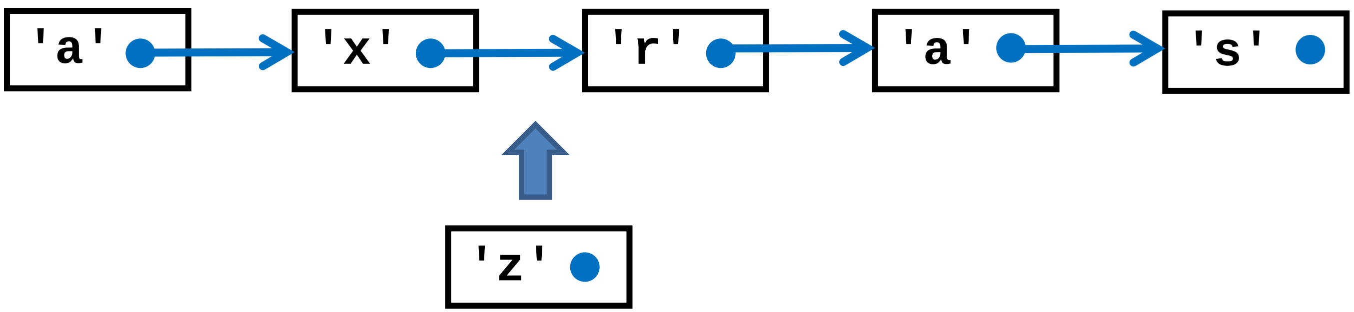
- Then re-assign head of linked list



```
/**
 * Inserts the specified element at the beginning of this list.
 *
 * @param c the character to add to the beginning of this list.
 */
public void addFirst(char c) {
  Node newNode = new Node(c);
  newNode.next = this.head;
  this.head = newNode;
  this.size++;
}
```

Adding to the middle of the list

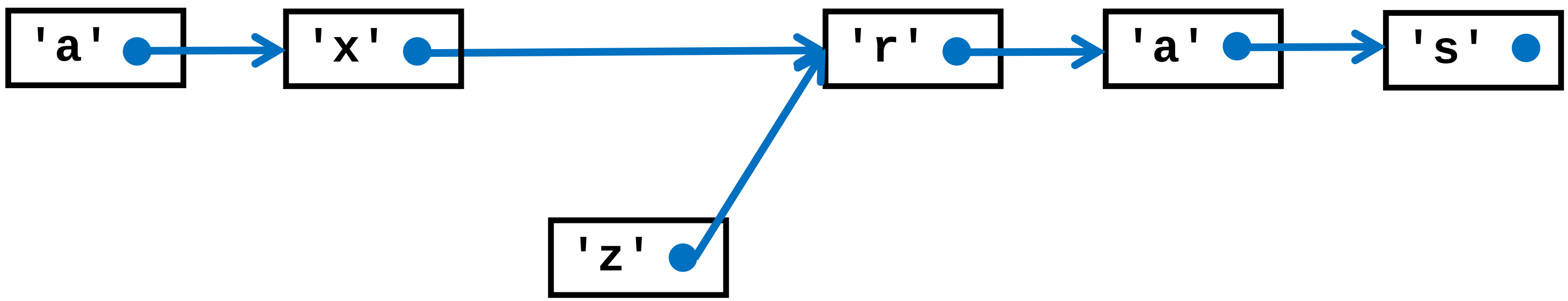
- Adding to the middle of the list



- **`t.add(2, 'z')`**

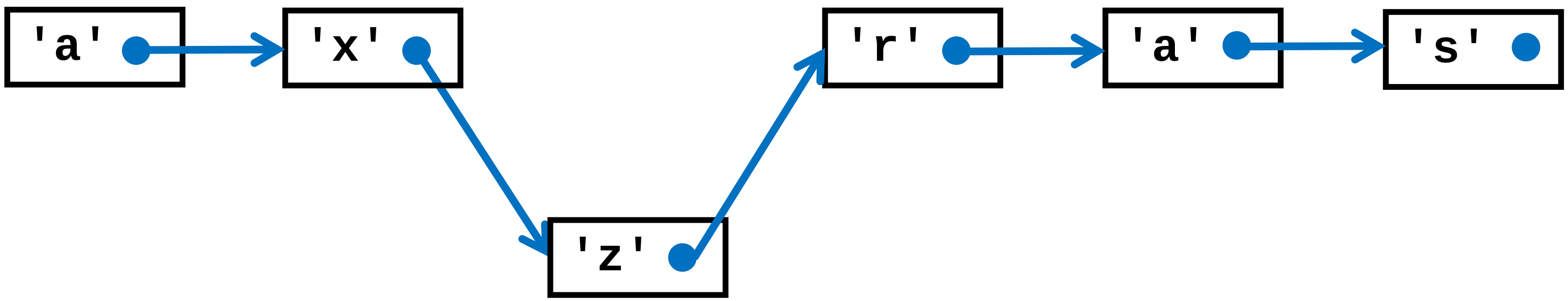
Adding to the middle of the list

- Must connect to the rest of the list



Adding to the middle of the list

- Then re-assign the link from the previous node



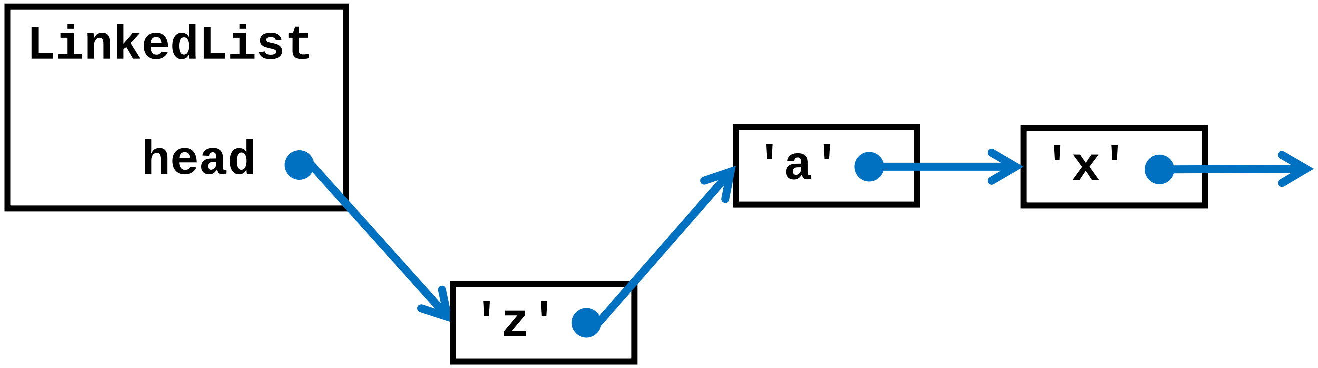
- Notice that we to know the node previous to the inserted node

```
/**
 * Insert an element at the specified index after the
 * specified node.
 *
 * @param index the index after prev to insert at
 * @param c the character to insert
 * @param prev the node to insert after
 */
private static void add(int index, char c, Node prev) {
  if (index == 0) {
    Node newNode = new Node(c);
    newNode.next = prev.next;
    prev.next = newNode;
    return;
  }
  LinkedList.add(index - 1, c, prev.next);
}
```

```
/**
 * Insert an element at the specified index in the list.
 *
 * @param index the index to insert at
 * @param c the character to insert
 */
public void add(int index, char c) {
  if (index < 0 || index > this.size) {
    throw new IndexOutOfBoundsException("Index: " + index + ", Size: "
          + this.size);
  }
  if (index == 0) {
    this.addFirst(c);
  }
  else {
    LinkedList.add(index - 1, c, this.head);
    this.size++;
  }
}
```

Removing from the front of the list

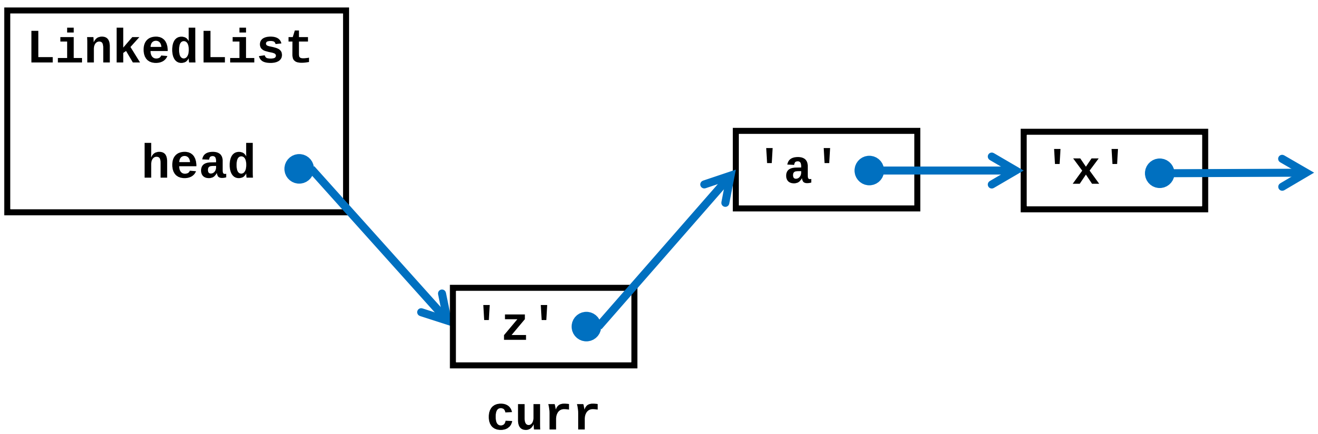
- Removing from the front of the list



- **`t.removeFirst()`** or **`t.remove(0)`**
- Also returns the element removed

Removing from the front of the list

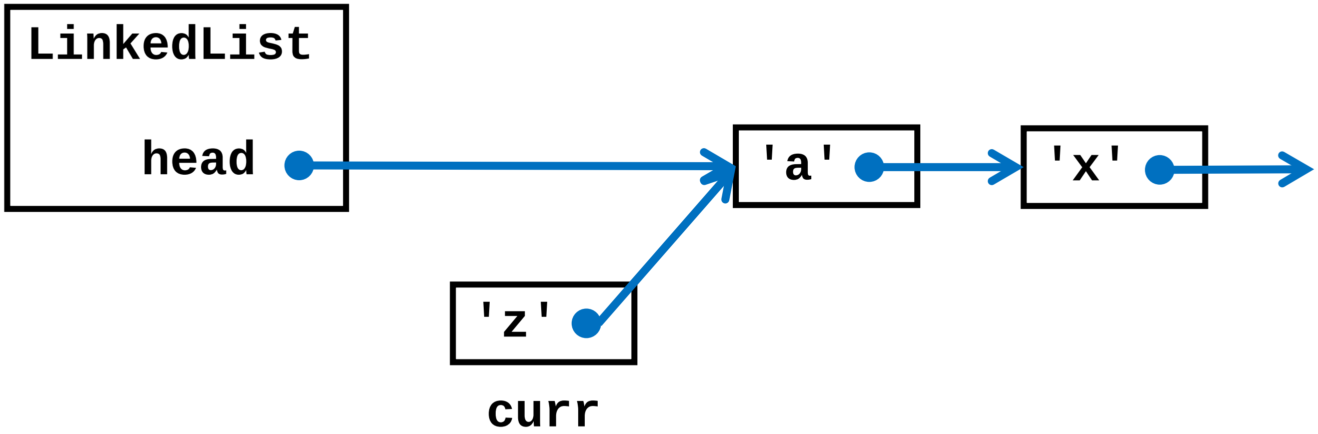
- Create a reference to the node we want to remove




```
Node curr = this.head;
```

Removing from the front of the list

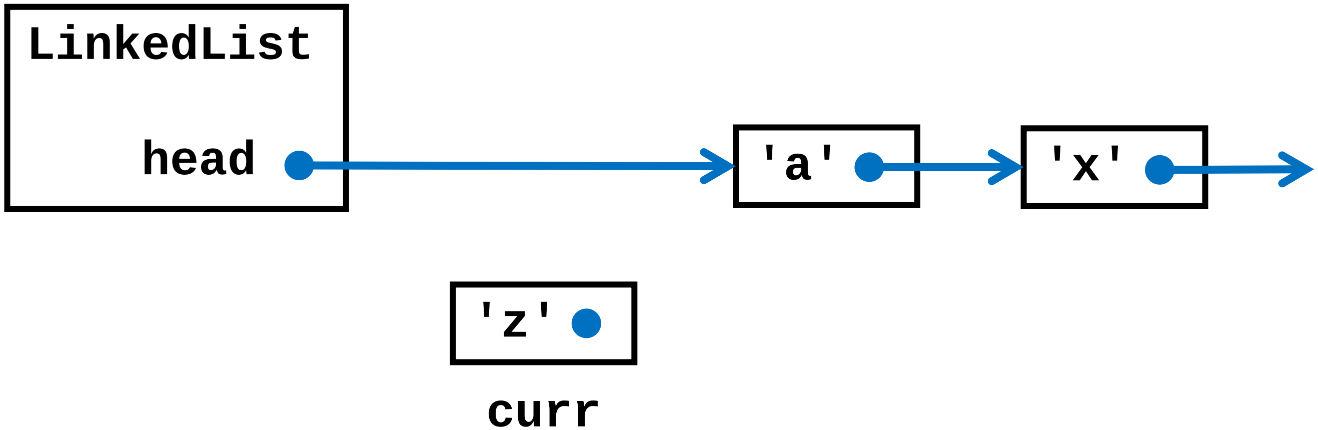
- Re-assign the head node




```
this.head = curr.next;
```

Removing from the front of the list

- Then remove the link from the old head node

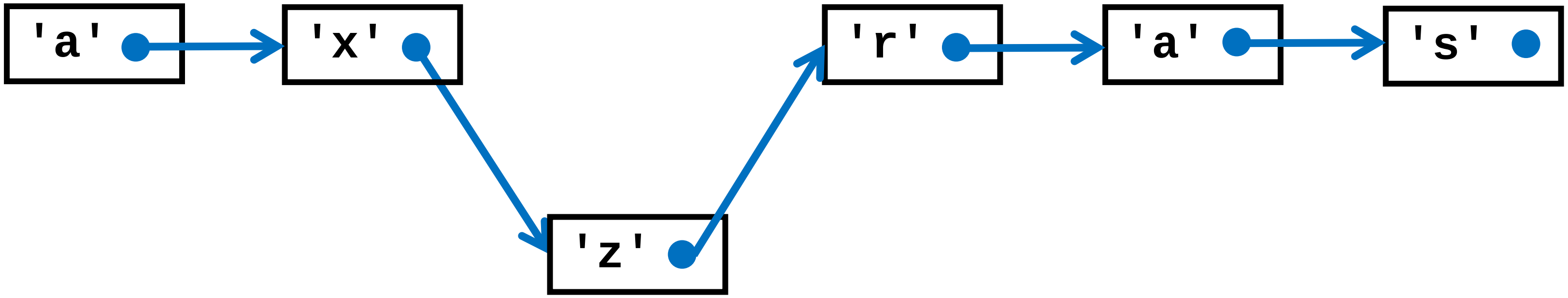



```
curr.next = null;
```

```java
/**
 * Removes and returns the first element from this list.
 *
 * @return the first element from this list
 */
public char removeFirst() {
  if (this.size == 0) {
    throw new NoSuchElementException();
  }
  Node curr = this.head;
  this.head = curr.next;
  curr.next = null;
  this.size--;
  return curr.data;
}
```

Removing from the middle of the list

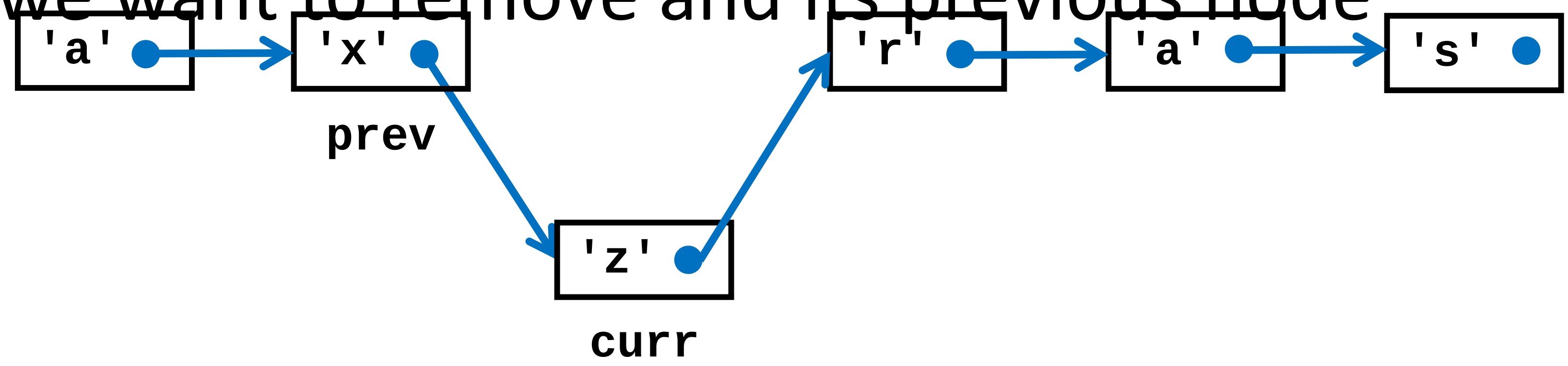
- Removing from the middle of the list




```
t.remove(2)
```

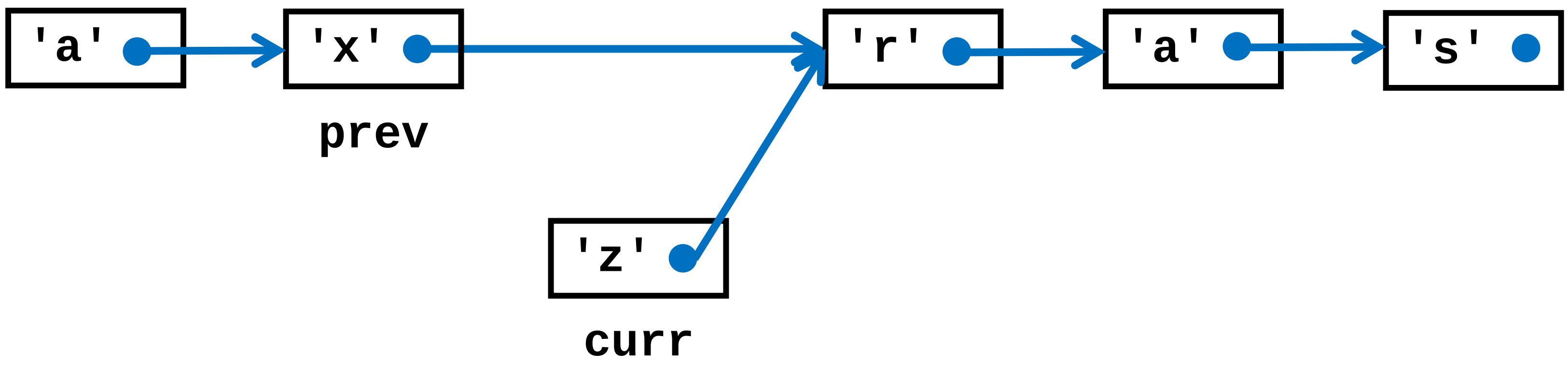
Removing from the middle of the list

- Assume that we have references to the node we want to remove and its previous node



Removing from the middle of the list

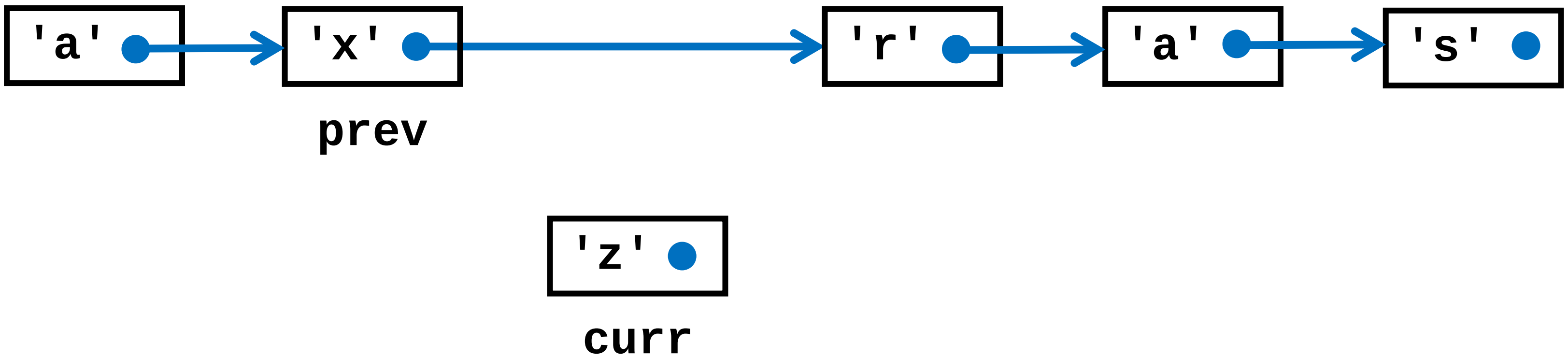
- Re-assign the link from the previous node




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

Removing from the middle of the list

- Then remove the link from the current node




```
curr.next = null;
```

```
/**
 * Removes the element at the specified position relative to the
 * current node.
 *
 * @param index
 *        the index relative to the current node of the
 *        element to be removed
 * @param prev
 *        the node previous to the current node
 * @param curr
 *        the current node
 * @return the element previously at the specified position
 */
private static char remove(int index, Node prev, Node curr) {
  if (index == 0) {
    prev.next = curr.next;
    curr.next = null;
    return curr.data;
  }
  return LinkedList.remove(index - 1, curr, curr.next);
}
```

```
/**
 * Removes the element at the specified position in this list
 *
 * @param index the index of the element to be removed
 * @return the element previously at the specified position
 */
public char remove(int index) {
  if (index < 0 || index >= this.size) {
    throw new IndexOutOfBoundsException("Index: " + index +
                                        ", Size: " + this.size);
  }
  if (index == 0) {
    return this.removeFirst();
  }
  else {
    char result = LinkedList.remove(index - 1, this.head, this.head.next);
    this.size--;
    return result;
  }
}
```