Lecture 18: A List Implementation That Links Data

CS 0445: Data Structures

Constantinos Costa

http://db.cs.pitt.edu/courses/cs0445/current.term/

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Advantages of Linked Implementation

- Uses memory only as needed
- When entry removed, unneeded memory returned to system
- Avoids moving data when adding or removing entries

Adding a Node at Various Positions

- Possible cases:
  - Chain is empty
  - Adding node at chain's beginning
  - Adding node between adjacent nodes
  - Adding node to chain's end

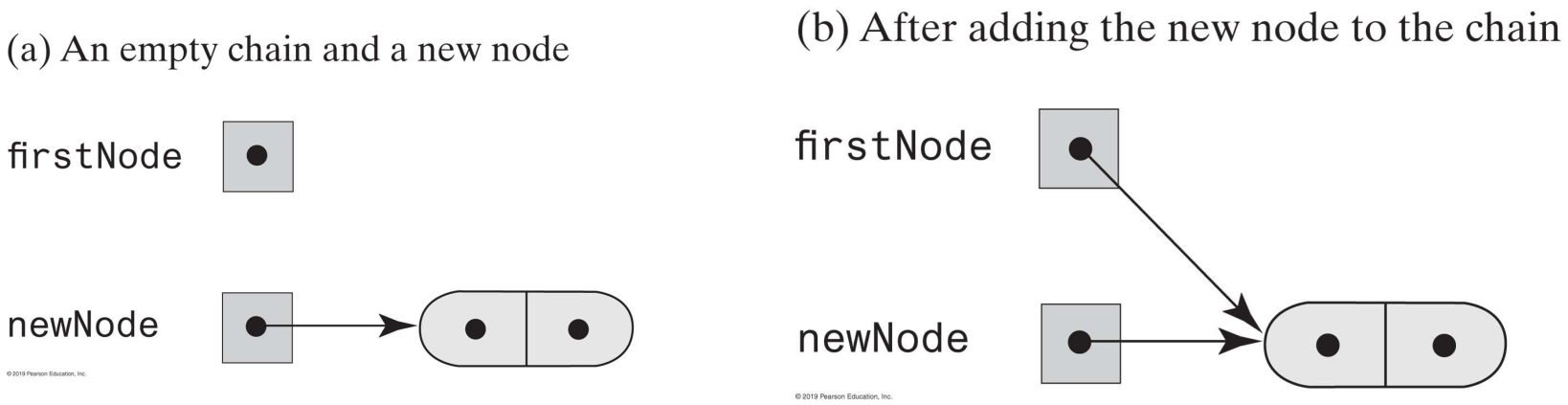
Adding a Node

- This pseudocode establishes a new node for the given data

newNode ***references a new instance of*** **Node**

Place **newEntry** ***in*** **newNode**

firstNode = ***address of*** **newNode**



Adding a node to an empty chain

Adding a Node

- This pseudocode describes the steps needed to add a node to the beginning of a chain.

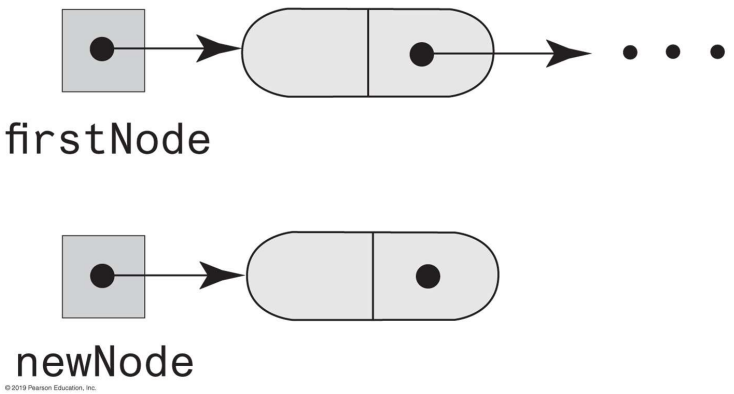
newNode ***references a new instance of*** **Node**

Place **newEntry** ***in*** **newNode**

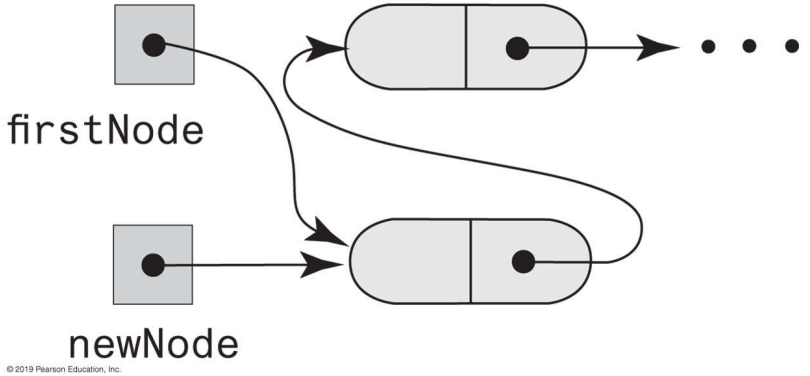
Set **newNode*'s link to*** **firstNode**

Set **firstNode** ***to*** **newNode**

(a) A chain of nodes and a new node



(b) After adding the new node to the beginning of the chain



Adding a node to the beginning of a chain

Adding a Node

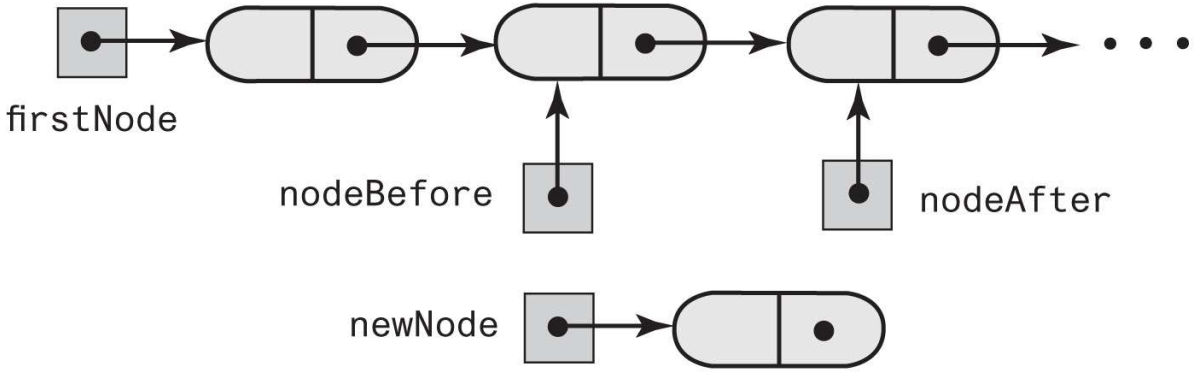
- Pseudocode to add a node to a chain between two existing, consecutive nodes

newNode ***references the new node***
Place **newEntry** ***in*** **newNode**
Let **nodeBefore** ***reference the node that will be before the new node***
Set **nodeAfter** ***to*** **nodeBefore** ***'s link***
Set **newNode** ***'s link to*** **nodeAfter**
Set **nodeBefore** ***'s link to*** **newNode**

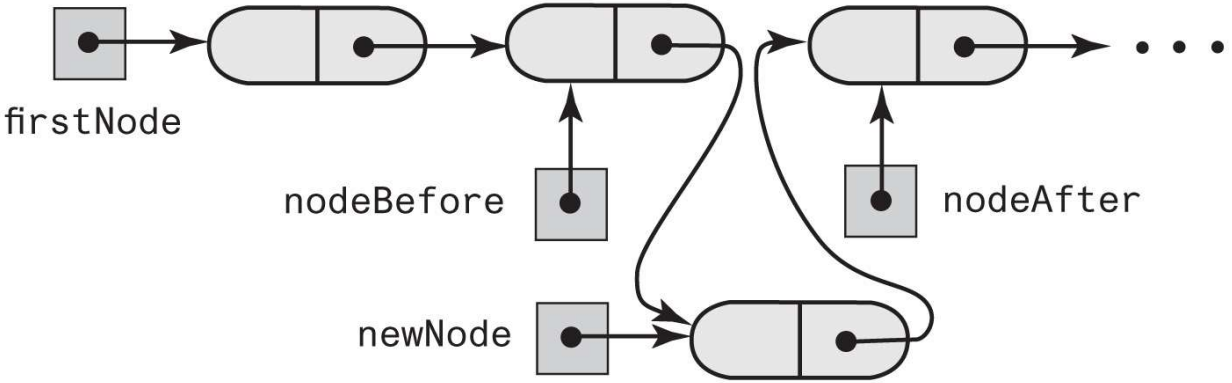
Adding a Node

Adding a node between two adjacent nodes

(a) A chain of nodes and a new node



(b) After adding the new node between adjacent nodes



Adding a Node

- Steps to add a node at the end of a chain.

newNode ***references a new instance of*** **Node**

Place **newEntry** ***in*** **newNode**

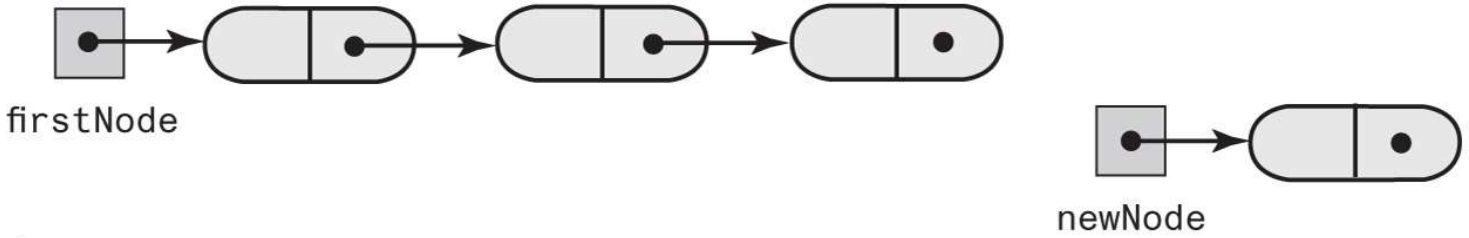
Locate the last node in the chain

Place the address of **newNode** ***in this last node***

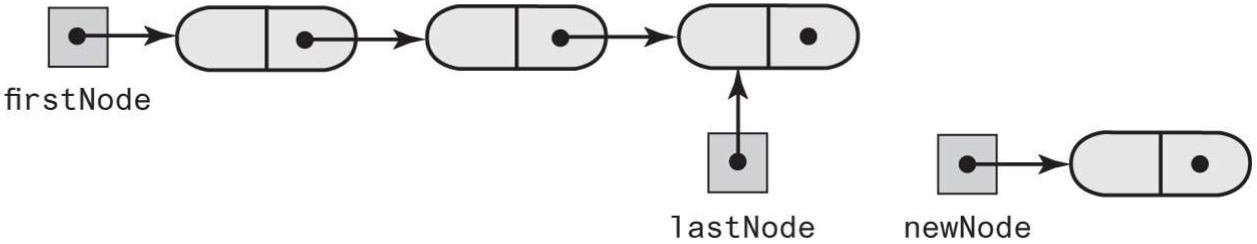
Adding a Node

Adding a node to the end of a chain

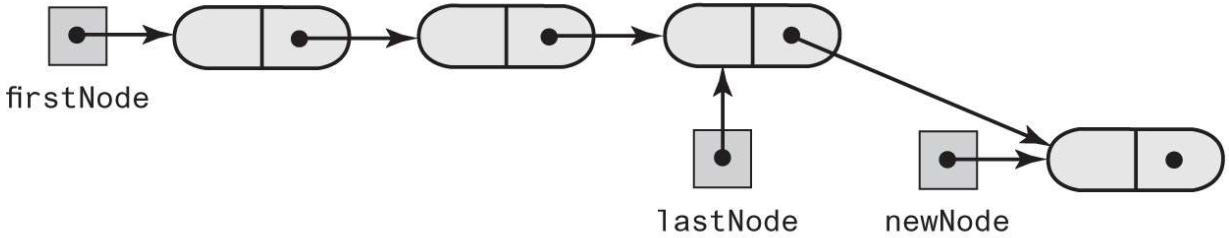
(a) A chain of nodes and a new node



(b) After locating the last node



(c) After adding the new node to the end of the chain



Removing a Node

- Possible cases
  - Removing the first node
  - Removing a node other than first one

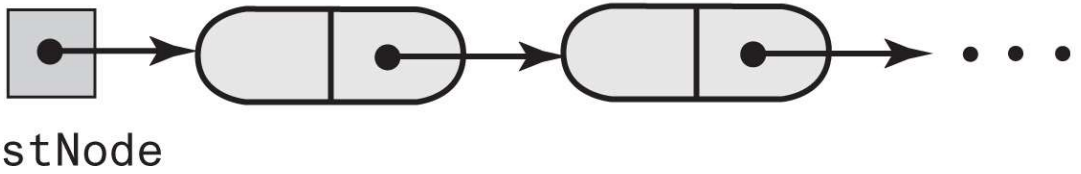
Removing a Node

- Steps for removing the first node.

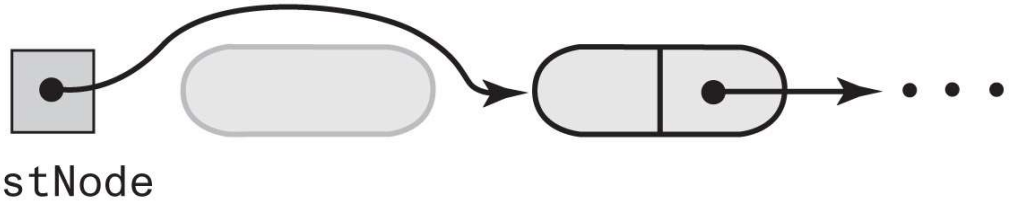
Set* firstNode *to the link in the first node;* firstNode *now either references the second node or is* null *if the chain had only one node.

Since all references to the first node no longer exist, the system automatically recycles the first node's memory.

(a) A chain of nodes



(b) After removing the first node



Removing the first node from a chain

Removing a Node

- Removing a node other than the first one.

Let **nodeBefore** *reference the node before the one to be removed.*

Set **nodeToRemove** *to* **nodeBefore***'s link;* **nodeToRemove** *now references the node to be removed.*

Set **nodeAfter** *to* **nodeToRemove***'s link;* **nodeAfter** *now either references the node after the one to be removed or is* **null.**

Set **nodeBefore***'s link to* **nodeAfter.** *(***nodeToRemove** *is now disconnected from the chain.)*

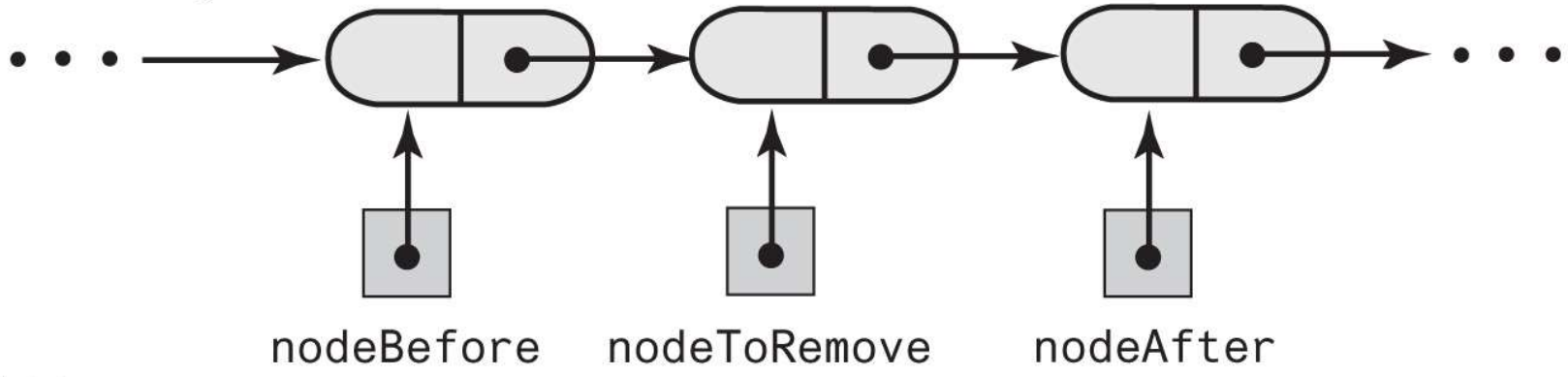
Set **nodeToRemove** *to* **null.**

Since all references to the disconnected node no longer exist, the system automatically recycles the node's memory.

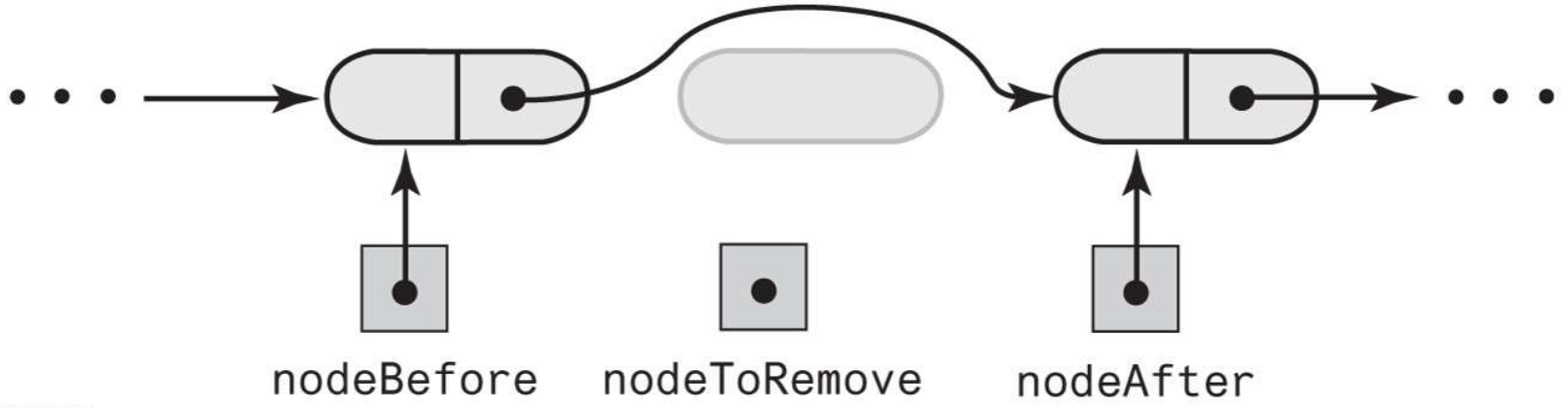
Removing a Node

- Removing an interior node from a chain

(a) After locating the node to remove



(b) After removing the node



Removing a Node

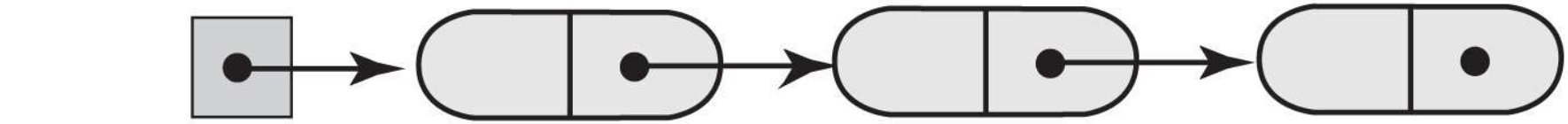
- Operations on a chain depended on the method `getNodeAt`

```
// Returns a reference to the node at a given position.
// Precondition: The chain is not empty;
//               1 <= givenPosition <= numberOfEntries.
private Node getNodeAt(int givenPosition)
{
  // Assertion: (firstNode != null) &&
  //         (1 <= givenPosition) && (givenPosition <= numberOfEntries)
  Node currentNode = firstNode;
  // Traverse the chain to locate the desired node
  // (skipped if givenPosition is 1)
  for (int counter = 1; counter < givenPosition; counter++)
    currentNode = currentNode.getNextNode();
  // Assertion: currentNode != null
  return currentNode;
} // end getNodeAt
```

Using a Tail Reference

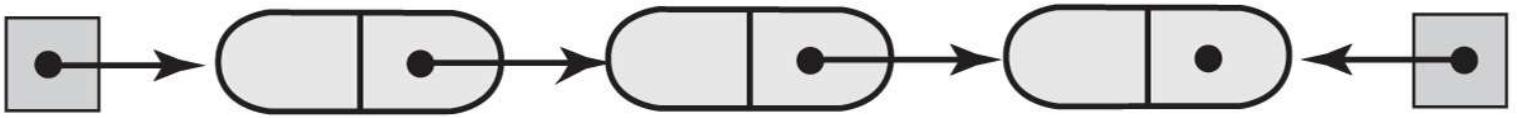
- Two linked chains

(a) With only a head reference



firstNode

(b) With both a head reference and a tail reference



firstNode

lastNode

Data Fields and Constructor (Part 1)

- An outline of the class `LList`

```
/** A linked implemention of the ADT list. */
public class LList<T> implements ListInterface<T>
{
      private Node firstNode;          // Reference to first node of chain
      private int  numberOfEntries;

      public LList()
      {
      initializeDataFields();
      } // end default constructor

      public void clear()
      {
      initializeDataFields();
      } // end clear

/*  < Implementations of the public methods add, remove, replace, getEntry, contains,
    getLength, isEmpty, and toArray go here. >
  . . . */

  // Initializes the class's data fields to indicate an empty list.
  private void initializeDataFields()
  {
      firstNode = null;
      numberOfEntries = 0;
  } // end initializeDataFields
```

Data Fields and Constructor (Part 2)

- An outline of the class `LList`

```
// Returns a reference to the node at a given position.
// Precondition: The chain is not empty;
//          1 <= givenPosition <= numberOfEntries.
private Node getNodeAt(int givenPosition)
{
  // Assertion: (firstNode != null) &&
  //          (1 <= givenPosition) && (givenPosition <= numberOfEntries)
  Node currentNode = firstNode;

  // Traverse the chain to locate the desired node
  // (skipped if givenPosition is 1)
  for (int counter = 1; counter < givenPosition; counter++)
    currentNode = currentNode.getNextNode();
  // Assertion: currentNode != null
  return currentNode;
} // end getNodeAt

   private class Node
   {
                              // < Implementation of private inner class Node >
         } // end Node

} // end LList
```

Adding to the End of the List

- The method `add` assumes method `getNodeAt`

```
public void add(T newEntry)
{
  Node newNode = new Node(newEntry);

  if (isEmpty())
    firstNode = newNode;
  else                        // Add to end of nonempty list
  {
    Node lastNode = getNodeAt(numberOfEntries);
    lastNode.setNextNode(newNode); // Make last node reference new node
  } // end if

  numberOfEntries++;
} // end add
```

Adding at a Given Position

- `add` method.

```
public void add(int givenPosition, T newEntry)
{
  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries + 1))
  {
    Node newNode = new Node(newEntry);
    if (givenPosition == 1)              // Case 1
    {
      newNode.setNextNode(firstNode);
      firstNode = newNode;
    }
    else                                              // Case 2: list is not empty
    {                              // and givenPosition > 1
      Node nodeBefore = getNodeAt(givenPosition - 1);
      Node nodeAfter = nodeBefore.getNextNode();
      newNode.setNextNode(nodeAfter);
      nodeBefore.setNextNode(newNode);
    } // end if
    numberOfEntries++;
  }
  else
    throw new IndexOutOfBoundsException(
          "Illegal position given to add operation.");
} // end add
```

Method `isEmpty`

```
public boolean isEmpty()
{
  boolean result;

  if (numberOfEntries == 0) // Or getLength() == 0
  {
    // Assertion: firstNode == null
    result = true;
  }
  else
  {
    // Assertion: firstNode != null
    result = false;
  } // end if

  return result;
} // end isEmpty
```

Method `toArray`

- Traverses chain, loads an array.

```
public T[] toArray()
{
  // The cast is safe because the new array contains null entries
  @SuppressWarnings("unchecked")
  T[] result = (T[])new Object[numberOfEntries];

  int index = 0;
  Node currentNode = firstNode;
  while ((index < numberOfEntries) && (currentNode != null))
  {
    result[index] = currentNode.getData();
    currentNode = currentNode.getNextNode();
    index++;
  } // end while

  return result;
} // end toArray
```

Testing Core Methods

- A main method that tests part of the implementation of the ADT list

```
public static void main(String[] args)
{
  System.out.println("Create an empty list.");
  ListInterface<String> myList = new LList<String>();
  System.out.println("List should be empty; isEmpty returns " +
                     myList.isEmpty() + ".");

  System.out.println("\nTesting add to end:");
  myList.add("15");
  myList.add("25");
  myList.add("35");
  myList.add("45");
  System.out.println("List should contain 15 25 35 45.");
  displayList(myList);
  System.out.println("List should not be empty; isEmpty() returns " +
                     myList.isEmpty() + ".");
  System.out.println("\nTesting clear():");
  myList.clear();
  System.out.println("List should be empty; isEmpty returns " +
                     myList.isEmpty() + ".");
} // end main
```

Testing Core Methods

- A main method that tests part of the implementation of the ADT list

Program Output

Create an empty list.
List should be empty; isEmpty returns true.

Testing add to end:
List should contain 15 25 35 45.
The list contains 4 entries, as follows:
15 25 35 45
List should not be empty; isEmpty() returns false.

Testing clear():
List should be empty; isEmpty returns true.

`remove` method returns entry it deletes from list

```
public T remove(int givenPosition){
  T result = null;                    // Return value
  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries))
  {
    // Assertion: !isEmpty()
    if (givenPosition == 1)           // Case 1: Remove first entry
    {
      result = firstNode.getData();       // Save entry to be removed
      firstNode = firstNode.getNextNode(); // Remove entry
    }
    else                              // Case 2: Not first entry
    {
      Node nodeBefore = getNodeAt(givenPosition - 1);
      Node nodeToRemove = nodeBefore.getNextNode();
      result = nodeToRemove.getData();    // Save entry to be removed
      Node nodeAfter = nodeToRemove.getNextNode();
      nodeBefore.setNextNode(nodeAfter);  // Remove entry
    } // end if
    numberOfEntries--;                // Update count
    return result;                    // Return removed entry
  }
  else
    throw new IndexOutOfBoundsException(
          "Illegal position given to remove operation.");
} // end remove
```

Continuing the Implementation

- Replacing a list entry requires us to replace the data portion of a node with other data.

```
public T replace(int givenPosition, T newEntry)
{
  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries))
  {
    // Assertion: !isEmpty()
    Node desiredNode = getNodeAt(givenPosition);
    T originalEntry = desiredNode.getData();
    desiredNode.setData(newEntry);
    return originalEntry;
  }
  else
    throw new IndexOutOfBoundsException(
          "Illegal position given to replace operation.");
} // end replace
```

Continuing the Implementation

- Retrieving a list entry is straightforward.

```
public T getEntry(int givenPosition)
{
  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries))
  {
    // Assertion: !isEmpty()
    return getNodeAt(givenPosition).getData();
  }
  else
    throw new IndexOutOfBoundsException(
          "Illegal position given to getEntry operation.");
} // end getEntry
```

Continuing the Implementation

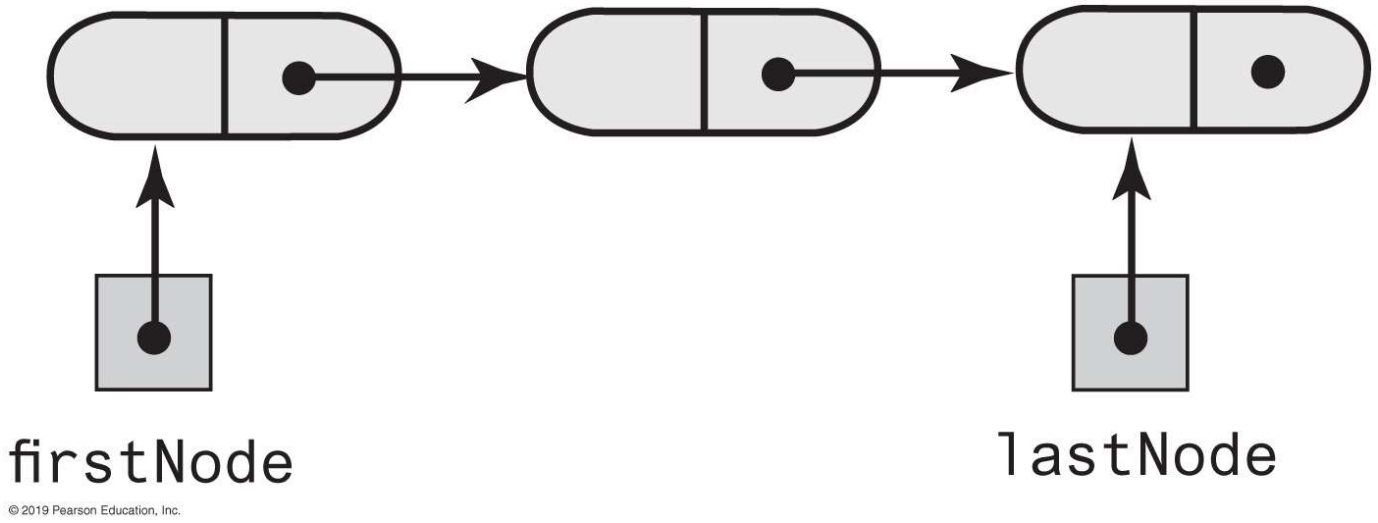
- Checking to see if an entry is in the list, the method `contains`.

```
public boolean contains(T anEntry)
{
  boolean found = false;
  Node currentNode = firstNode;

  while (!found && (currentNode != null))
  {
    if (anEntry.equals(currentNode.getData()))
      found = true;
    else
      currentNode = currentNode.getNextNode();
  } // end while

  return found;
} // end contains
```

A Refined Linked Implementation

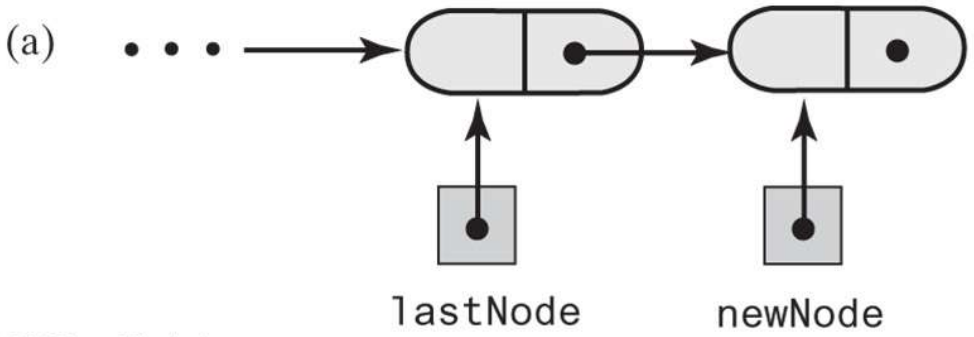
- A linked chain with both a head reference and a tail reference

```
private Node firstNode;       // Head reference to first node
private Node lastNode;        // Tail reference to last node
private int  numberOfEntries; // Number of entries in list
```

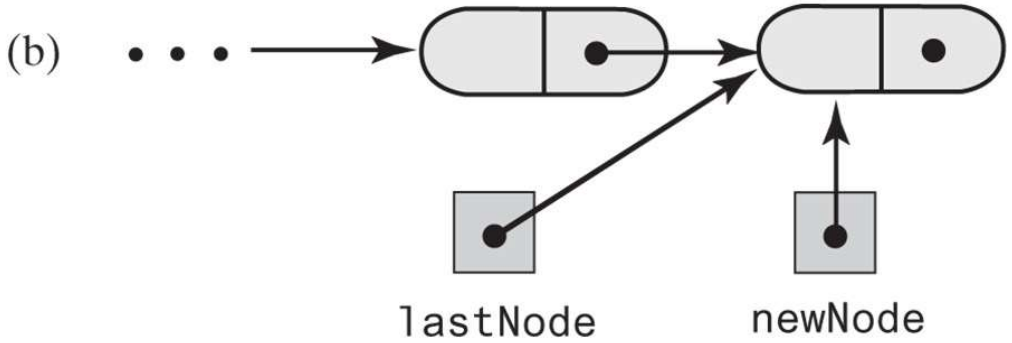


A Refined Linked Implementation

- Adding a node to the end of a nonempty chain that has a tail reference



After executing
`lastNode.setNextNode(newNode);`



After executing
`lastNode = newNode;`

A Refined Linked Implementation

- Revision of the first `add` method

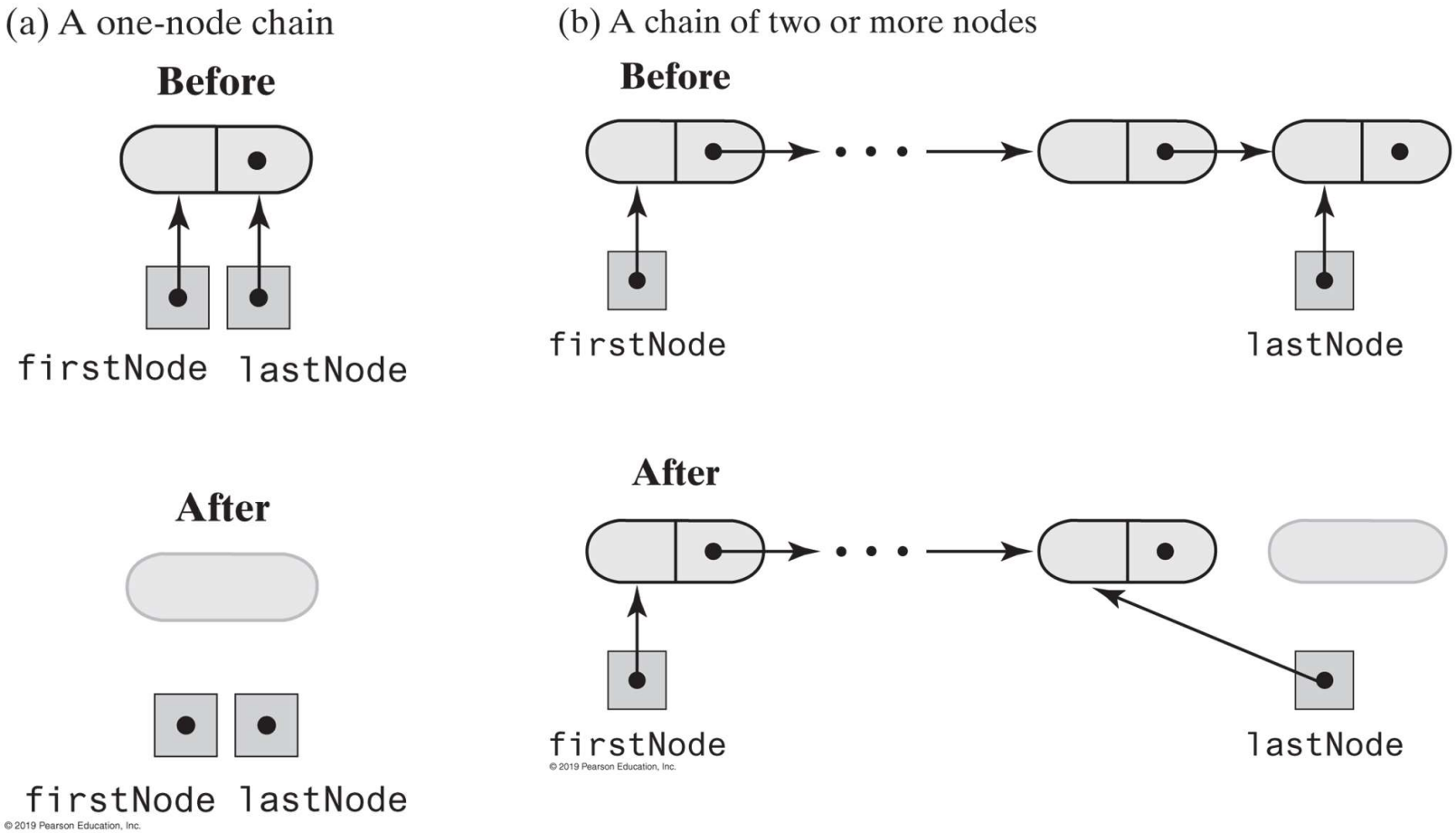
```
public void add(T newEntry)
{
  Node newNode = new Node(newEntry);

  if (isEmpty())
    firstNode = newNode;
  else
    lastNode.setNextNode(newNode);

  lastNode = newNode;
  numberOfEntries++;
} // end add
```

A Refined Linked Implementation - refined add by position

```
public void add(int givenPosition, T newEntry) {
  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries + 1))
  {
    Node newNode = new Node(newEntry);
    if (isEmpty())     {
      firstNode = newNode;
      lastNode = newNode;
    }
    else if (givenPosition == 1)     {
      newNode.setNextNode(firstNode);
      firstNode = newNode;
    }
    else if (givenPosition == numberOfEntries + 1)     {
      lastNode.setNextNode(newNode);
      lastNode = newNode;
    }
    else {
      Node nodeBefore = getNodeAt(givenPosition - 1);
      Node nodeAfter = nodeBefore.getNextNode();
      newNode.setNextNode(nodeAfter);
      nodeBefore.setNextNode(newNode);
    } // end if
    numberOfEntries++;
  }
  else
    throw new IndexOutOfBoundsException(
          "Illegal position given to add operation.");
} // end add
```

A Refined Linked Implementation

- Before and after removing the last node from a chain that has both head and tail references and contains one or more nodes



A Refined Linked Implementation — refined `remove`

```
public T remove(int givenPosition) {
  T result = null;                    // Return value
  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries)) {
  // Assertion: !isEmpty()
    if (givenPosition == 1)           // Case 1: Remove first entry
    {
      result = firstNode.getData();   // Save entry to be removed
      firstNode = firstNode.getNextNode();
      if (numberOfEntries == 1)
        lastNode = null;              // Solitary entry was removed
    }
    else                              // Case 2: Not first entry
    {
      Node nodeBefore = getNodeAt(givenPosition - 1);
      Node nodeToRemove = nodeBefore.getNextNode();
      Node nodeAfter = nodeToRemove.getNextNode();
      nodeBefore.setNextNode(nodeAfter);
      result = nodeToRemove.getData();
      if (givenPosition == numberOfEntries)
        lastNode = nodeBefore;        // Last node was removed
    } // end if
    numberOfEntries--;
  }
  else
    throw new IndexOutOfBoundsException(
          "Illegal position given to remove operation.");

  return result;                      // Return removed entry
} // end remove
```

Efficiency of Using a Chain

- The time efficiencies of the ADT list operations for three implementations, expressed in Big Oh notation

Operation	Alist	LList	LListWithTail
`add(newEntry)`	O(1)	O(*n*)	O(1)
`add(givenPosition, newEntry)`	O(*n*); O(n); O(1)	O(1); O(*n*)	O(1); O(*n*); O(1)
`toArray()`	O(*n*)	O(*n*)	O(*n*)
`remove(givenPosition)`	O(*n*); O(*n*); O(1)	O(1); O(*n*)	O(1); O(*n*)
`replace(givenPosition, newEntry)`	O(1)	O(1); O(*n*)	O(1); O(*n*); O(1)
`getEntry(givenPosition)`	O(1)	O(1); O(*n*)	O(1); O(*n*); O(1)
`contains(anEntry)`	O(*n*)	O(*n*)	O(*n*)
`clear(), getLength(), isEmpty()`	O(1)	O(1)	O(1)

Java Class Library: The Class `LinkedList`

- Implements the interface **`List`**
- **`LinkedList`** defines more methods than are in the interface `List`
- You can use the class **`LinkedList`** as implementation of ADT
  - **queue**
  - **deque**
  - or **list**.