Northeastern University

Lecture 12: A Bag Implementation that Links Data - 1

Prof. Chen-Hsiang (Jones) Yu, Ph.D.

College of Engineering

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Problems with Array Implementation

- Array has a fixed size.
- May become full.
- Alternatively, may have wasted space.
- Resizing is possible but requires overhead of time.

Alternative Approach?!

- Introduces a new data organization that uses memory only as needed for a new entry.
- Returns the unneeded memory to the system after an entry is removed.

Analogy

- Empty classroom
- Numbered desks stored in hallway
  - Number on **back** of desk is the “address”
- Number on **desktop** references another desk in chain of desks
- Desks are linked by the numbers

Analogy

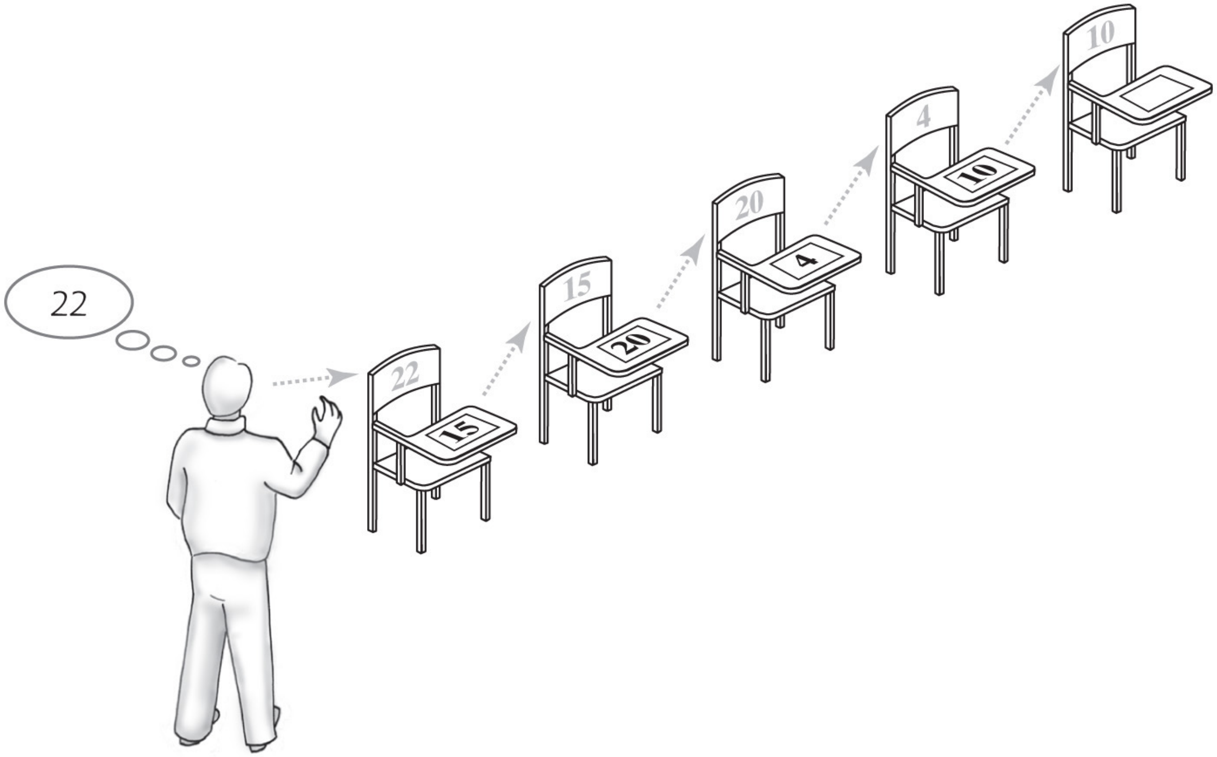


Figure 3-1: A chain of five desks

Forming a Chain by Adding to Its Beginning

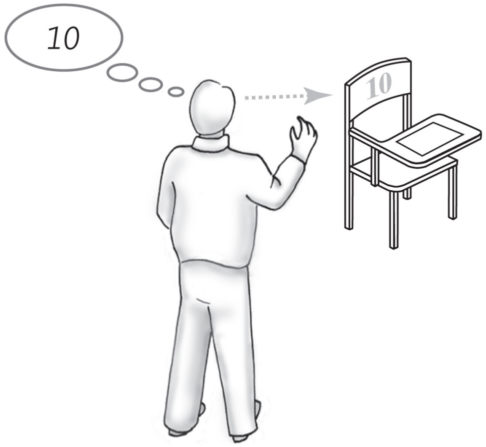


Figure 3-2: One desk in the room

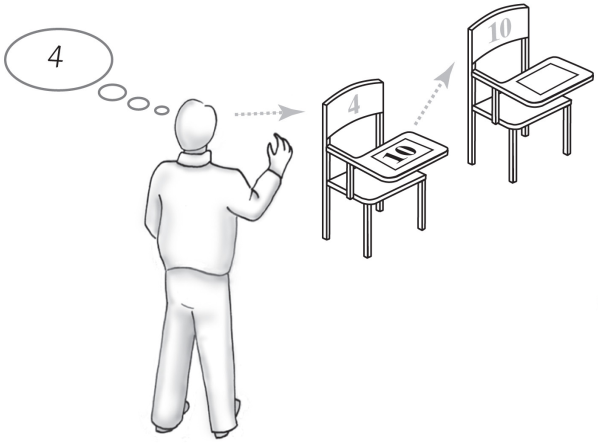


Figure 3-3: Two linked desks, with the newest desk first

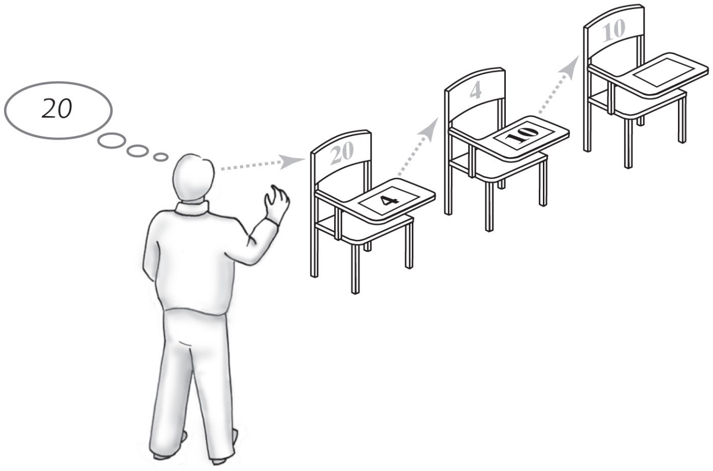


Figure 3-4: Three linked desks, with the newest desk first.

Question

- The instructor knows the address of only one desk.
  - A. Where in the chain is that desk?
    - First
    - Last
    - Somewhere else
  - B. Who is sitting at that desk?
    - the student who arrived first
    - the student who arrived last
    - Someone else

Answer

- The instructor knows the address of only one desk.
  - A. Where in the chain is that desk?
    - First
    - Last
    - Somewhere else
  - B. Who is sitting at that desk?
    - the student who arrived first
    - the student who arrived last
    - Someone else

Forming a Chain by Adding to Its Beginning

```
// Process the first student
newDesk represents the new student’s desk
New student sits at newDesk
Instructor memorizes the address of newDesk

// Process the remaining students
while (students arrive)
{
    newDesk represents the new student’s desk
    New student sits at newDesk

    Write the instructor’s memorized address on newDesk
    Instructor memorizes the address of newDesk
}
```

Pseudocode details the steps taken to form a chain of desks

The Private Class **Node**

```
private class Node
{
   private T    data; // Entry in bag
   private Node next; // Link to next node

   private Node(T dataPortion)
   {
      this(dataPortion, null);
   } // end constructor

   private Node(T dataPortion, Node nextNode)
   {
      data = dataPortion;
      next = nextNode;
   } // end constructor

 } // end Node
```

Listing 3-1: The private inner class **Node**

The Private Class `Node`

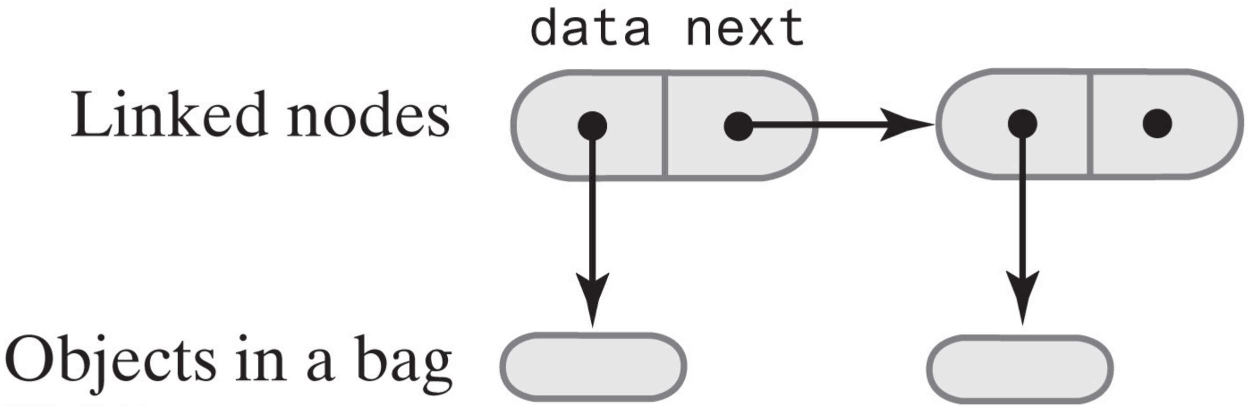


Figure 3-5: Two linked nodes that each reference object data

An Outline of the Class LinkedBag - Part 1

```
/** A class of bags whose entries are stored in a chain
    of linked nodes. The bag is never full. */

public class LinkedBag<T> implements BagInterface<T>
{
   private Node firstNode; // reference to first node
   private int numberOfEntries;

   public LinkedBag()
   {
      firstNode = null;
      numberOfEntries = 0;
   } // end default constructor

   // . . .
```

Listing 3-2: An outline of the class LinkedBag

An Outline of the Class **LinkedBag** - Part 2

```
   private class Node
   {
      private T    data; // Entry in bag
      private Node next; // Link to next node

      private Node(T dataPortion)
      {
        this(dataPortion, null);
      } // end constructor

      private Node(T dataPortion, Node nextNode)
      {
        data = dataPortion;
        next = nextNode;
      } // end constructor
   } // end Node

} // end LinkedBag
```

Listing 3-2: An outline of the class **LinkedBag**

Beginning a Chain of Nodes

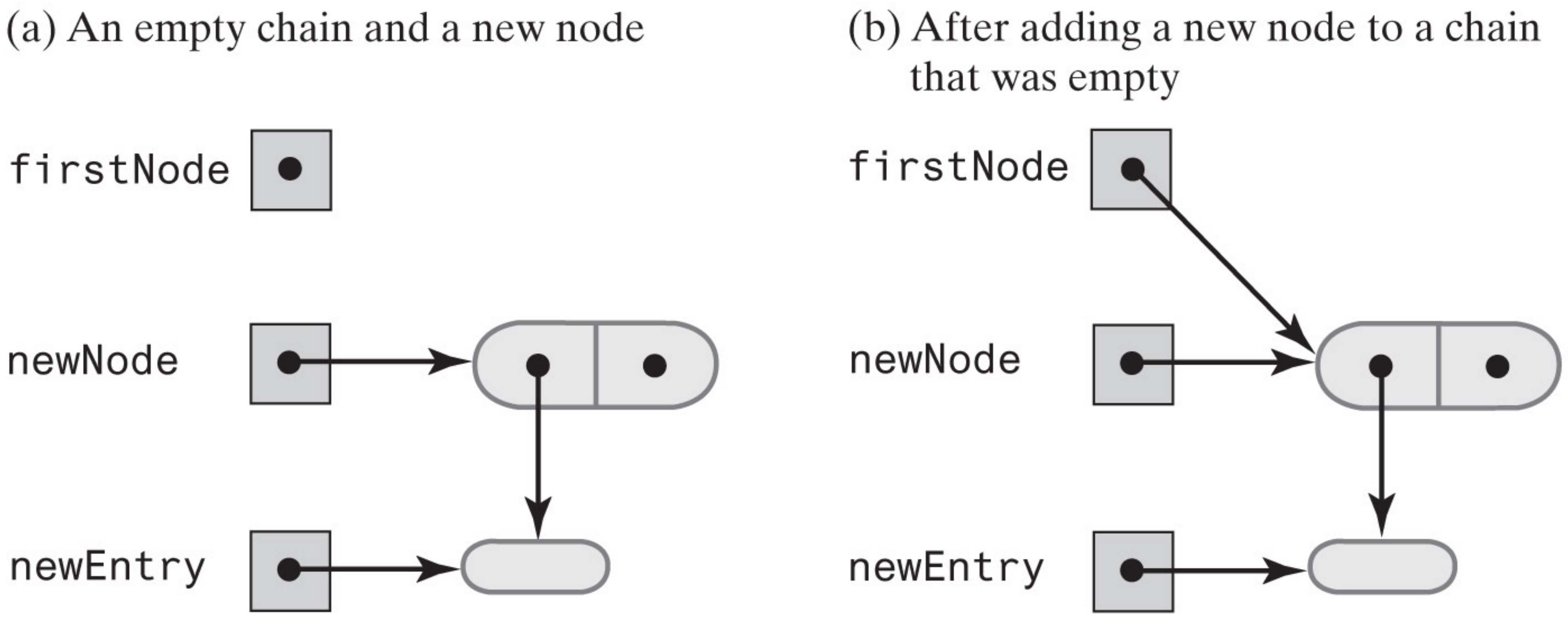

(a) An empty chain and a new node
(b) After adding a new node to a chain that was empty
firstNode
newNode
newEntry
firstNode
newNode
newEntry

Figure 3-6: Adding a new node to an empty chain. (a) An empty chain and a new node; (b) after adding a new node to a chain that was empty

Beginning a Chain of Nodes

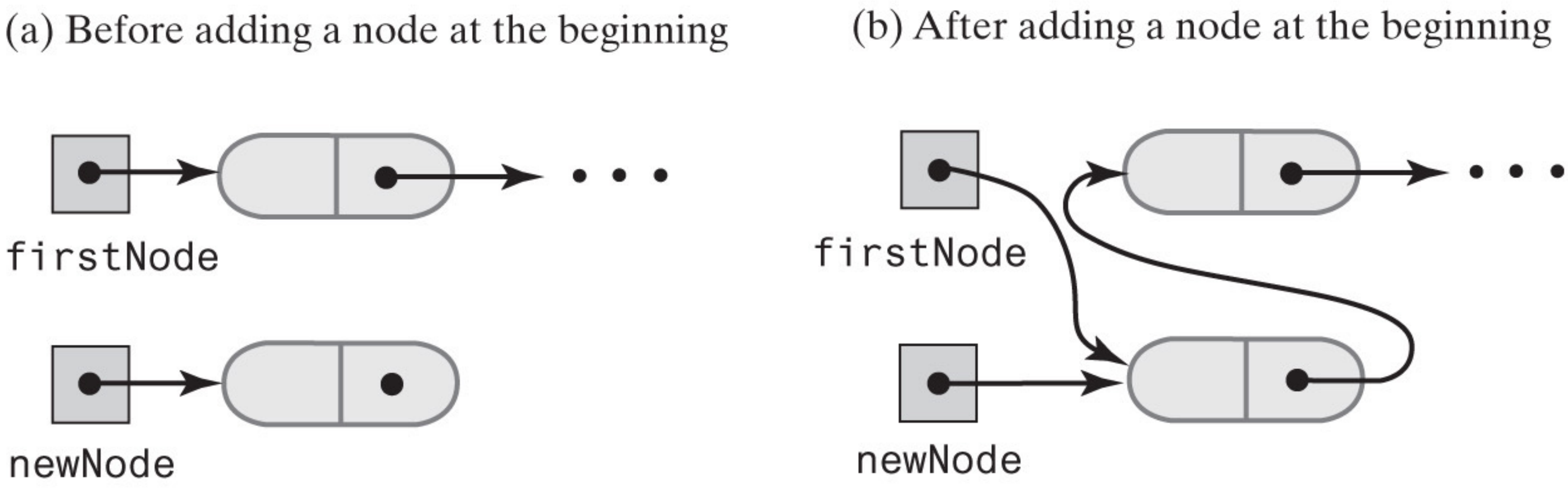

(a) Before adding a node at the beginning
firstNode
newNode
(b) After adding a node at the beginning
firstNode
newNode

Figure 3-7: A chain of nodes just before and just after adding a node at the beginning. (a) Before adding a node at the beginning; (b) After adding a node at the beginning.

Beginning a Chain of Nodes

```
/** Adds a new entry to this bag.
    @param newEntry  The object to be added as a new entry.
    @return  True. */
public boolean add(T newEntry) // OutOfMemoryError possible
{
   // Add to beginning of chain:
   Node newNode = new Node(newEntry);
   newNode.next = firstNode;  // Make new node reference rest of chain
                              // (firstNode is null if chain is empty)
   firstNode = newNode;       // New node is at beginning of chain
   numberOfEntries++;

   return true;
} // end add
```

The method `add`

Method `toArray`

```java
/** Retrieves all entries that are in this bag.
    @return  A newly allocated array of all the entries in the bag. */
public T[] toArray()
{
   // The cast is safe because the new array contains null entries
   @SuppressWarnings("unchecked")
   T[] result = (T[])new Object[numberOfEntries]; // Unchecked cast

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

   return result;
} // end toArray
```

The method `toArray` returns an array of the entries currently in a bag

Question

- In the previous definition of `toArray`, the `while()` statement uses following Boolean expression to control the loop.

```
(index < numberOfEntries) && (currentNode != null)
```

- Is it necessary to involve the values of both `index` and `currentNode`? Why?

Answer

- Testing the value of both `index` and `currentNode` is not necessary.
- Although testing either of these values is sufficient, testing both values provides a check against mistakes in your code.

Testing the Core Methods

Test Program - Part 1

```
/** A test of the methods add, toArray, isEmpty, and getCurrentSize,
    as defined in the first draft of the class LinkedBag. */
public class LinkedBagDemo1
{
   public static void main(String[] args)
   {
      System.out.println("Creating an empty bag.");
      BagInterface<String> aBag = new LinkedBag1<>();
      testIsEmpty(aBag, true);
      displayBag(aBag);

      String[] contentsOfBag = {"A", "D", "B", "A", "C", "A", "D"};
      testAdd(aBag, contentsOfBag);
      testIsEmpty(aBag, false);
   } // end main
```

Listing 3-3: A sample program that tests some methods in the class `LinkedBag`

Test Program - Part 2

```
// Tests the method isEmpty.
// Precondition: If bag is empty, the parameter empty should be true;
// otherwise, it should be false.
private static void testIsEmpty(BagInterface<String> bag, boolean empty)
{
   System.out.print("\nTesting isEmpty with ");
   if (empty)
      System.out.println("an empty bag:");
   else
      System.out.println("a bag that is not empty:");

   System.out.print("isEmpty finds the bag ");
   if (empty && bag.isEmpty())
      System.out.println("empty: OK.");
   else if (empty)
      System.out.println("not empty, but it is: ERROR.");
   else if (!empty && bag.isEmpty())
      System.out.println("empty, but it is not empty: ERROR.");
   else
      System.out.println("not empty: OK.");
} // end testIsEmpty
```

Listing 3-3: A sample program that tests some methods in the class **LinkedBag**

Test Program - Part 3

```java
// Tests the method add.
private static void testAdd(BagInterface<String> aBag, String[] content)
{
   System.out.print("Adding the following strings to the bag: ");
   for (int index = 0; index < content.length; index++)
   {
      if (aBag.add(content[index]))
         System.out.print(content[index] + " ");
      else
         System.out.print("\nUnable to add " + content[index] +
                          " to the bag.");
   } // end for
   System.out.println();

   displayBag(aBag);
} // end testAdd
```

Listing 3-3: A sample program that tests some methods in the class `LinkedBag`

Test Program - Part 4

```
  // Tests the method toArray while displaying the bag.
   private static void displayBag(BagInterface<String> aBag)
   {
      System.out.println("The bag contains the following string(s):");
      Object[] bagArray = aBag.toArray();
      for (int index = 0; index < bagArray.length; index++)
      {
         System.out.print(bagArray[index] + " ");
      } // end for

      System.out.println();
   } // end displayBag

} // end LinkedBagDemo1
```

Listing 3-3: A sample program that tests some methods in the class **`LinkedBag`**

Test Program - Result

Program Output

```
Creating an empty bag.

Testing isEmpty with an empty bag:
isEmpty finds the bag empty: OK.
The bag contains the following string(s):

Adding the following strings to the bag: A D B A C A D
The bag contains the following string(s):
D A C A B D A

Testing isEmpty with a bag that is not empty:
isEmpty finds the bag not empty: OK.
```

Method getFrequencyOf

```java
/** Counts the number of times a given entry appears in this bag.
    @param anEntry  The entry to be counted.
    @return  The number of times anEntry appears in the bag. */
public int getFrequencyOf(T anEntry)
{
   int frequency = 0;
   int loopCounter = 0;
   Node currentNode = firstNode;

   while ((loopCounter < numberOfEntries) && (currentNode != null))
   {
      if (anEntry.equals(currentNode.data))
      {
         frequency++;
      } // end if

      loopCounter++;
      currentNode = currentNode.next;
   } // end while

   return frequency;
} // end getFrequencyOf
```

Counts the number of times a given entry appears

Method `contains`

```java
/** Tests whether this bag contains a given entry.
    @param anEntry  The entry to locate.
    @return  True if the bag contains anEntry, or false otherwise */

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

   while (!found && (currentNode != null))
   {
      if (anEntry.equals(currentNode.data))
         found = true;
      else
         currentNode = currentNode.next;
   } // end while
   return found;
} // end contains
```

Determine whether a bag contains a given entry

Question

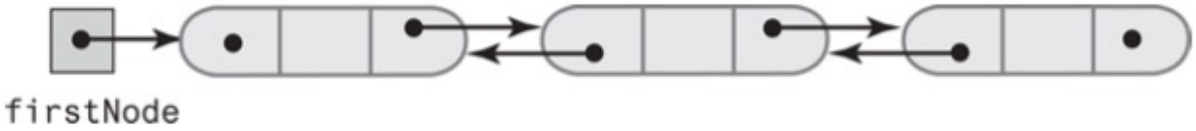
- If `currentNode` in the previous method `contains()` becomes `null`, what value does the method return when the bag is not empty?

Answer

- The method returns `false`.
- If `currentNode` becomes `null`, the entire chain has been searched without success.

Exercise

- In a doubly linked chain, each node can reference the previous node as well as the next node. Following figure shows a doubly linked chain and its head reference.



- Define a class to represent a node in a doubly linked chain. Write the class as an inner class of a class that implements the ADT bag. You can omit set and get methods.

Answer

```
private class DoublyLinkedNode
{
    private T data; // Entry in bag
    private DoublyLinkedNode next; // Link to next node
    private DoublyLinkedNode previous; // Link to previous node

    private DoublyLinkedNode(T dataPortion)
    {
        this(dataPortion, null, null);
    } // end constructor

    private DoublyLinkedNode(T dataPortion, DoublyLinkedNode nextNode,
                            DoublyLinkedNode previousNode)
    {
        data = dataPortion;
        next = nextNode;
        previous = previousNode;
    } // end constructor
} // end DoublyLinkedNode
```