The List ADT
Objectives

• Examine list processing and various ordering techniques
• Define a list abstract data type
• Examine various list implementations
• Compare list implementations
Lists

• A list is a linear collection, like a stack and queue, but more flexible: adding and removing elements from a list does \textit{not} have to happen at one end or the other

• We will examine three types of list collections:
  • \textit{ordered} lists
  • \textit{unordered} lists
  • \textit{indexed} lists
Ordered Lists

• **Ordered list**: Its elements are ordered by some inherent characteristic of the elements

• **Examples**:
  • Names in alphabetical order
  • Numeric scores in ascending order

• So, the elements themselves determine where they are stored in the list
New values must be inserted so that the ordering of the list is maintained.
Unordered Lists

- **Unordered list**: the order of the elements in the list is *not* based on a characteristic of the elements, but is determined by the *user* of the list.

- A new element can be put
  - on the front of the list
  - or on the rear of the list
  - or after a particular element already in the list

- **Examples**: shopping list, to-do list, …
Conceptual View of an Unordered List

New values can be inserted anywhere in the list
Indexed Lists

- **Indexed list**: elements are referenced by their *numeric position* in the list, called its *index*

- It is the *position* in the list that is important, and the user can determine the order that the items go in the list

- Every time the list changes, the *position* (index) of an element may change

- **Example**: current first-place holder in the bobsled race
Conceptual View of an Indexed List

New values can be inserted at any position in the list
List Operations

• Operations common to all list types include:
  • *Adding/Removing* elements in various ways
  • *Checking the status* of the list (*isEmpty*, *size*)
  • *Iterating through* the elements in the list (more on this later!)

• The key differences between the list types involve the way elements are *added*:
  • To an *ordered* list?
  • To an *unordered* list?
  • To an *indexed* list?
The Common Operations on a List

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>removeFirst</td>
<td>Removes the first element from the list</td>
</tr>
<tr>
<td>removeLast</td>
<td>Removes the last element from the list</td>
</tr>
<tr>
<td>remove</td>
<td>Removes a particular element from the list</td>
</tr>
<tr>
<td>first</td>
<td>Examines the element at the front of the list</td>
</tr>
<tr>
<td>last</td>
<td>Examines the element at the rear of the list</td>
</tr>
<tr>
<td>contains</td>
<td>Determines if a particular element is in the list</td>
</tr>
<tr>
<td>isEmpty</td>
<td>Determines whether the list is empty</td>
</tr>
<tr>
<td>size</td>
<td>Determines the number of elements in the list</td>
</tr>
<tr>
<td>iterator</td>
<td>Returns an iterator for the list’s elements</td>
</tr>
<tr>
<td>toString</td>
<td>Returns a string representation of the list</td>
</tr>
</tbody>
</table>
## Operation Particular to an Ordered List

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>add</td>
<td>Adds an element to the list (in the correct place)</td>
</tr>
</tbody>
</table>
# Operations Particular to an Unordered List

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>addToFront</td>
<td>Adds an element to the front of the list</td>
</tr>
<tr>
<td>addToRear</td>
<td>Adds an element to the rear of the list</td>
</tr>
<tr>
<td>addAfter</td>
<td>Adds an element after a particular element already in the list</td>
</tr>
</tbody>
</table>
# Operations Particular to an Indexed List

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>add</td>
<td>Adds an element at a particular index in the list</td>
</tr>
<tr>
<td>set</td>
<td>Sets the element at a particular index in the list overwriting any element that was there</td>
</tr>
<tr>
<td>get</td>
<td>Returns a reference to the element at the specified index</td>
</tr>
<tr>
<td>indexOf</td>
<td>Returns the index of the specified element</td>
</tr>
<tr>
<td>remove</td>
<td>Removes and returns the element at a particular index</td>
</tr>
</tbody>
</table>
List Operations

• We use Java interfaces to formally define the operations on the lists, as usual
• Note that interfaces can be defined via inheritance (derived from other interfaces)
  • Define the common list operations in one interface
    • See ListADT.java
  • Derive the thee others from it
    • see OrderedListADT.java
    • see UnorderedListADT.java
    • see IndexedListADT.java
ListADT Interface

```java
import java.util.Iterator;
public interface ListADT<T> {

    // Removes and returns the first element from this list
    public T removeFirst ();
    // Removes and returns the last element from this list
    public T removeLast ();
    // Removes and returns the specified element from this list
    public T remove (T element);
    // Returns a reference to the first element on this list
    public T first ();
    // Returns a reference to the last element on this list
    public T last ();
    // cont’d..
}
```
// ..cont’d

// Returns true if this list contains the specified target element
public boolean contains (T target);

// Returns true if this list contains no elements
public boolean isEmpty( );

// Returns the number of elements in this list
public int size( );

// Returns an iterator for the elements in this list
public Iterator<T> iterator( );

// Returns a string representation of this list
public String toString( );
}
public interface OrderedListADT<T> extends ListADT<T> {
    // Adds the specified element to this list at the proper location
    public void add (T element);
}
public interface UnorderedListADT<T> extends ListADT<T> {
    // Adds the specified element to the front of this list
    public void addToFront (T element);

    // Adds the specified element to the rear of this list
    public void addToRear (T element);

    // Adds the specified element after the specified target
    public void addAfter (T element, T target);
}
IndexedListADT

public interface IndexedListADT<T> extends ListADT<T> {
   // Inserts the specified element at the specified index
   public void add (int index, T element);
   // Sets the element at the specified index
   public void set (int index, T element);
   // Adds the specified element to the rear of this list
   public void add (T element);
   // Returns a reference to the element at the specified index
   public T get (int index);
   // Returns the index of the specified element
   public int indexOf (T element);
   // Removes and returns the element at the specified index
   public T remove (int index);
}
Discussion

• Note that the **add** method in the IndexedList ADT is overloaded

• So is the **remove** method
  • Why? Because there is a **remove** method in the parent ListADT
    • This is *not* overriding, because the parameters are different
List Implementation using Arrays

- Container is an array
- Fix one end of the list at index 0 and shift *as needed* when an element is added or removed
- Is a shift needed when an element is added
  - at the front?
  - somewhere in the middle?
  - at the end?
- Is a shift needed when an element is removed
  - from the front?
  - from somewhere in the middle?
  - from the end?
An Array Implementation of a List

An array-based list \texttt{ls} with 4 elements

\begin{figure}
\centering
\begin{tikzpicture}
  \node (ls) at (0,0) [draw, rounded corners] {\texttt{ls}};
  \node (list) at (ls) [below=1cm] {list 4};
  \node (rear) at (ls) [below left=1cm] {rear};
  \draw[->,green] (ls) -- (list);
  \draw[->,green] (ls) -- (rear);
  \node at (1.5,0) [draw] {0 1 2 3 4 5 \ldots \ ?}
  \node at (1.5,-1) [draw] {\phantom{0 1 2 3 4 5 \ldots \ ?}};
\end{tikzpicture}
\end{figure}
public T remove (T element) throws ElementNotFoundException
{
    T result;
    int index = find (element);  // uses helper method find
    if (index == NOT_FOUND)
        throw new ElementNotFoundException("list");
    result = list[index];
    rear--;
    // shift the appropriate elements
    for (int scan=index; scan < rear; scan++)
        list[scan] = list[scan+1];
    list[rear] = null;
    return result;
}
private int find(T target) {
    int scan = 0, result = NOT_FOUND;
    boolean found = false;
    if (!isEmpty())
        while (!found && scan < rear)
            if (target.equals(list[scan]))
                found = true;
            else
                scan++;
    if (found)
        result = scan;
    return result;
}
public boolean contains (T target)
{
    return (find(target) != NOT_FOUND);
    //uses helper method find
}
// Adds the specified Comparable element to the list, keeping the elements in sorted order.

public void add (T element) {
    if (size( ) == list.length)
        expandCapacity( );
    Comparable<T> temp = (Comparable<T>)element;
    int scan = 0;
    while (scan < rear && temp.compareTo(list[scan]) > 0)
        scan++;
    for (int scan2=rear; scan2 > scan; scan2--)
        list[scan2] = list[scan2-1]
    list[scan] = element;
    rear++;
}
The **Comparable** Interface

- For an ordered list, the *actual* class for the generic type `T` *must* have a way of comparing elements so that they can be ordered
  - So, it must implement the **Comparable** interface, *i.e.* it must define a method called `compareTo`
- But, the *compiler* does not know whether or not the class that we use to fill in the generic type `T` will have a `compareTo` method
The Comparable Interface

- So, to make the compiler happy:
  - Declare a variable that is of type `Comparable<T>`
  - Convert the variable of type `T` to the variable of type `Comparable<T>`

```java
Comparable<T> temp = (Comparable<T>)element;
```

- Note that an object of a class that implements `Comparable` can be referenced by a variable of type `Comparable<T>`
List Implementation Using Arrays, Method 2: *Circular Arrays*

- Recall circular array implementation of queues

- *Exercise*: implement list operations using a circular array implementation
List Implementation Using Links

• We can implement a list collection with a linked list as the container
  • Implementation uses techniques similar to ones we've used for stacks and queues
• We will first examine the remove operation for a singly-linked list implementation
• Then we’ll look at the remove operation for a doubly-linked list, for comparison
public T remove (T targetElement) throws ElementNotFoundException {
    if (isEmpty( ))
        throw new ElementNotFoundException ("List");
    boolean found = false;
    LinearNode<T> previous = null
    LinearNode<T> current = head;
    // cont’d..
while (current != null && !found)
    if (targetElement.equals (current.getElement( )))
        found = true;
    else
    {
        previous = current;
        current = current.getNext( );
    }
if (!found)
    throw new ElementNotFoundException ("List");

if (size ( ) == 1)
    head = tail = null;
else
    if (current.equals (head))
        head = current.getNext( );
else
    // cont’d
if (current.equals(tail)) {
    tail = previous;
    tail.setNext(null);
}
else {
    previous.setNext(current.getNext());
    count--;
    return current.getElement();
}
Doubly Linked Lists

• A **doubly linked list** has **two** references in each node:
  • One to the **next** element in the list
  • One to the **previous** element
• This makes moving back and forth in a list easier, and eliminates the need for a **previous** reference in particular algorithms
• **Disadvantage**? a bit more overhead when managing the list
Implementation of a Doubly-Linked List

A doubly-linked list $dl$ with 4 elements
• See `DoubleNode.java`

• We can then implement the `ListADT` using a doubly linked list as the container

• Following our usual convention, this would be called `DoublyLinkedList.java`
/------------------------------------------------------------------
// Removes and returns the specified element.
//------------------------------------------------------------------

public T remove (T element) throws ElementNotFoundException
{
    T result;
    DoubleNode<T> nodeptr = find (element);
        // uses helper method find for doubly-linked list
    if (nodeptr == null)
        throw new ElementNotFoundException ("list");
    result = nodeptr.getElement();
        // check to see if front or rear
    if (nodeptr == front)
        result = this.removeFirst();
        // cont’d.

The remove( ) operation (doubly-linked list)
else
    if (nodeptr == rear)
        result = this.removeLast();
    else
    {
        nodeptr.getNext().setPrevious(nodeptr.getPrevious());
        nodeptr.getPrevious().setNext(nodeptr.getNext());
        count--;
    }

    return result;
}
Analysis of List Implementations

• In both array and linked implementations, many operations are similar in efficiency.

• Most are $O(1)$, except when shifting or searching need to occur, in which case they are order $O(n)$
  
  • Exercise: determine the time complexity of each operation

• In particular situations, the frequency of the need for *particular operations* may guide the use of one approach over another.