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 not have to happen at one end or the other.

• We will examine three types of list collections:
  • ordered lists
  • unordered lists
  • 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’s 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:
  • 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>
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<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</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*
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);
}

OrderedList ADT
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);
}

UnorderedListADT
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
<<interface>>
ListADT

removeFirst( )
removeLast( )
remove(T)
first( )
last( )
contains(T)
isEmpty( )
size( )
iterator( )
toString( )

<<interface>>
IndexedListADT

add(T)
add(int, T)
set(int, T)
get(int)
indexOf(T)
remove(int)

<<interface>>
UnorderedListADT

addToFront(T)
addToRear(T)
addAfter(element:T, target:T)

<<interface>>
OrderedListADT

add(Comparable)
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 `ls` with 4 elements
UML Diagram for **ArrayList**

<table>
<thead>
<tr>
<th>ArrayList</th>
</tr>
</thead>
<tbody>
<tr>
<td>rear</td>
</tr>
<tr>
<td>list</td>
</tr>
<tr>
<td>NOT_FOUND</td>
</tr>
<tr>
<td>DEFAULT_CAPACITY</td>
</tr>
</tbody>
</table>

- removeFirst( )
- removeLast( )
- remove(T element)
- first( )
- last( )
- contains()
- isEmpty( )
- size( )
- iterator( )
- toString( )
- find( )
- expandCapacity( )

<table>
<thead>
<tr>
<th>&lt;&lt;interface&gt;&gt;</th>
</tr>
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<tr>
<td>ListADT</td>
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- removeFirst( )
- removeLast( )
- remove(T element)
- first( )
- last( )
- contains()
- isEmpty( )
- size( )
- iterator( )
- toString( )

**Class ArrayList** will be **extended** to yield classes **ArrayOrderedList**, **ArrayUnorderedList**, etc.
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;
}
// Returns true if this list contains the specified element.
//
public boolean contains (T target) {
    return (find(target) != NOT_FOUND);
    //uses helper method find
}
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 add( ) operation of ArrayOrderedList
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>`

```
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
    
The remove( ) operation (cont’d)
if (current.equals(tail)) {
    tail = previous;
    tail.setNext(null);
}
else
    previous.setNext(current.getNext());

count--;
return current.getElement();

The remove() operation (cont’d)
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`
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.
}
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.