COMP9024: Data Structures and Algorithms

Week Four: Lists and Iterators

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Outline

- Array lists
- Node lists
- Iterators

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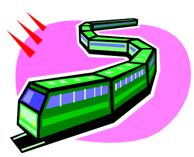
Lists



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Lists

- A list is a collection of elements of the same type that are stored in a certain linear order.
- An element can be accessed, inserted or removed.
- Two types of lists:
  - Array lists
  - Node lists

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Array List ADT

- A list that supports access to its elements by their indices.
- The List ADT extends the notion of array by storing a sequence of arbitrary objects.
- An element can be accessed, inserted or removed by specifying its index.
- An exception is thrown if an incorrect rank is specified (e.g., a negative rank)

- Main methods:
  - get(i): Return the element with index i.
  - set(i, e): Replace with e and return the element at index i.
  - add(i, e): Insert a new element e at index i.
  - remove(i): Remove the element at index i.

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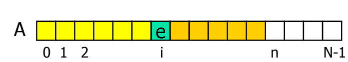
Array-Based Implementation

- Use an array A of size N.
- A variable n keeps track of the size of the list (the number of elements stored).
- Method get(i) is implemented in O(1) time by returning A[i].
- Method set(i, e) is implemented in O(1) time by setting A[i] to e.



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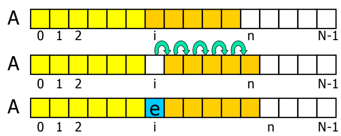
Insertion (1/2)

- In method add(i, e), we need to make room for the new element by shifting forward the $n - i$ elements $A[i], \ldots, A[n - 1]$.
- In the worst case ($i = 0$), this takes $O(n)$ time.

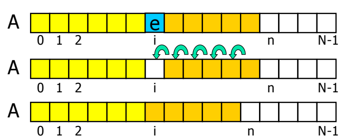


Insertion (2/2)

```
Algorithm add(i, e)
{
  for ( j = n-1, n-2, … , i )
    A[j+1]=A[j];
  A[i]=e;
  n=n+1;
}
```


Deletion(1/2)

- In method remove(i) , we need to fill the hole left by the removed element by shifting backward the $n - i - 1$ elements $A[i + 1], \ldots, A[n - 1]$.
- In the worst case ($i = 0$), this takes $O(n)$ time.



Deletion (2/2)

```
Algorithm remove(i)
{
  e=A[i];
  for ( j = i, i+1, … , n-2 )
    A[j]=A[j+1];
  n=n-1;
  return e;
}
```


A Simple Interface

```
public interface IndexList<E> {
    /** Returns the number of elements in this list. */
    public int size();
    /** Returns whether the list is empty. */
    public boolean isEmpty();
    /** Inserts an element e to be at index i, shifting all elements after this. */
    public void add(int i, E e) throws IndexOutOfBoundsException;
    /** Returns the element at index i, without removing it. */
    public E get(int i) throws IndexOutOfBoundsException;
    /** Removes and returns the element at index i, shifting the elements
     after this. */
    public E remove(int i) throws IndexOutOfBoundsException;
    /** Replaces the element at index i with e, returning the previous element
     at i. */
    public E set(int i, E e) throws IndexOutOfBoundsException;
}
```


Extendable-Array-Based Array Lists (1/4)

- In an add operation, when the array is full, instead of throwing an exception, we can replace the array with a larger one.
- How large should the new array be?
  - Incremental strategy: increase the size by a constant c.
  - Doubling strategy: double the size.

```
Algorithm add(i, e)
{ if ( size = N)
   { create a new array B with size 2N;
     for ( j = 0, 1, … , size-1)
       B[j]=A[j];
     A = B;
     N=2N;
   }
  insert e in A at i;
  size=size+1;
}
```

Extendable-Array-Based Array Lists (2/4)

```
/** Realization of an indexed list by means of an array, which is doubled when
the size of the indexed list exceeds the capacity of the array. */
public class ArrayIndexList<E> implements IndexList<E> {
  private E[] A; // array storing the elements of the indexed list
  private int capacity = 16; // initial length of array A
  private int size = 0; // number of elements stored in the indexed list /** Creates
the indexed list with initial capacity 16. */
  public ArrayIndexList() {
    A = (E[]) new Object[capacity]; // the compiler may warn, but this is ok
  }
```


Extendable-Array-Based Array Lists (3/4)

```
/** Inserts an element at the given index. */
public void add(int r, E e) throws IndexOutOfBoundsException {
  checkIndex(r, size() + 1);
  if (size == capacity) // an overflow
    { capacity *= 2; E[] B =(E[]) new Object[capacity];
      for (int i=0; i<size; i++) B[i] = A[i];
      A = B;
    }
   for (int i=size-1; i>=r; i--) // shift elements up
     A[i+1] = A[i];
   A[r] = e;
   size++; }
```


Extendable-Array-Based Array Lists (4/4)

```
/** Removes the element stored at the given index. */
public E remove(int r) throws IndexOutOfBoundsException {
  checkIndex(r, size());
  E temp = A[r];
  for (int i=r; i<size-1; i++) // shift elements down
    A[i] = A[i+1];
  size--;
  return temp; }
```


Comparison of the Strategies

- We compare the incremental strategy and the doubling strategy by analyzing the total time $T(n)$ needed to perform a series of n push operations.
  - A push operation is to add an element at the end of the list.
- We assume that we start with an empty list represented by an array of size 1.
- We call amortized time of a push operation the average time taken by a push over the series of operations, i.e., $T(n)/n$.

Incremental Strategy Analysis

- We replace the array $k = n/c$ times.
- The total time $T(n)$ of a series of n push operations is proportional to

  $n + c + 2c + 3c + 4c + \ldots + kc$

  $= n + c(1 + 2 + 3 + \ldots + k)$

  $= n + ck(k + 1)/2.$
- Since c is a constant, $T(n)$ is $O(n + k^2)$, i.e., $O(n^2)$.
- The amortized time of a push operation is $O(n)$.

Doubling Strategy Analysis

- We replace the array $k = \log n$ times.
- The total time $T(n)$ of a series of n push operations is proportional to

  $n + 1 + 2 + 4 + 8 + \ldots + 2^k$

  $= n + 2^{k+1} - 1 = 2n - 1.$
- $T(n)$ is $O(n)$.
- The amortized time of a push operation is $O(1)$.

Position ADT

- The Position ADT models the notion of place within a data structure where a single object is stored
- It gives a unified view of diverse ways of storing data, such as
  - a cell of an array
  - a node of a linked list
- Just one method:
  - object element(): returns the element stored at the position

Java Interface for the Position ADT

```
public interface Position<E> {
/** Return the element stored at this position. */
 E element(); }
```


Node List ADT

- The Node List ADT models a sequence of positions storing arbitrary objects
- It establishes a before/after relation between positions
- Generic methods:
  - size(), isEmpty()

Accessor methods:
- first(), last()
- prev(p), next(p)

- Update methods:
  - set(p, e)
  - addBefore(p, e), addAfter(p, e),
  - addFirst(e), addLast(e)
  - remove(p)

Java Interface for the Node List ADT (1/2)

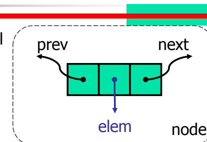
```
public interface PositionList<E> {
      /** Returns the number of elements in this list. */
     public int size();
      /** Returns whether the list is empty. */
     public boolean isEmpty();
      /** Returns the first node in the list. */
     public Position<E> first();
      /** Returns the last node in the list. */
     public Position<E> last();
      /** Returns the node after a given node in the list. */
     public Position<E> next(Position<E> p) throws InvalidPositionException,
      BoundaryViolationException;
      /** Returns the node before a given node in the list. */
     public Position<E> prev(Position<E> p) throws InvalidPositionException,
      BoundaryViolationException;
```

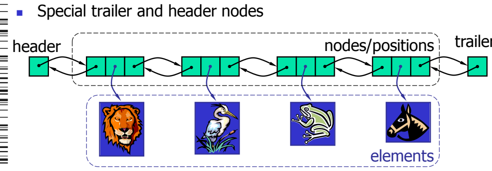

Java Interface for the Node List ADT (2/2)

```
   /** Inserts an element at the front of the list, returning new position. */
      public void addFirst(E e);
  /** Inserts an element at the end of the list, returning new position. */
public void addLast(E e);
  /** Inserts an element after the given node in the list. */
public void addAfter(Position<E> p, E e) throws InvalidPositionException;
  /** Inserts an element before the given node in the list. */
public void addBefore(Position<E> p, E e) throws InvalidPositionException;
  /** Removes a node from the list, returning the element stored there. */
public E remove(Position<E> p) throws InvalidPositionException;
  /** Replaces the element stored at the given node, returning old element. */
public E set(Position<E> p, E e) throws InvalidPositionException;
 }
```


Doubly Linked List Implementation

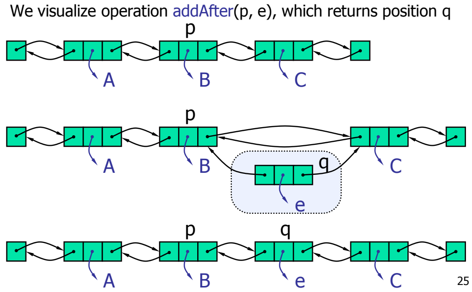
- A doubly linked list provides a natural implementation of the Node List ADT
- Nodes implement Position and store:
  - element
  - link to the previous node
  - link to the next node
- Special trailer and header nodes





Insertion

- We visualize operation addAfter(p, e), which returns position q

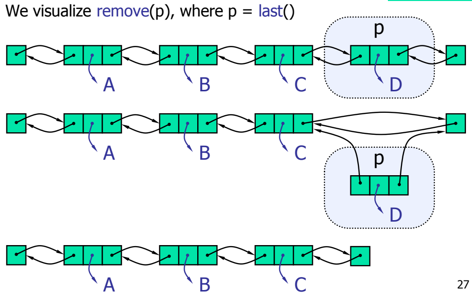


Insertion Algorithm

Algorithm insertAfter(*p*,*e*)
{
Create a new node *v*;
v.setElement(*e*);
v.setPrev(*p*); // link *v* to its predecessor
v.setNext(*p*.getNext()); // link *v* to its successor
(*p*.getNext()).setPrev(*v*); // link *p*'s old successor to *v*
p.setNext(*v*); // link *p* to its new successor, *v*
return *v*; // the position for the element *e*
}

Deletion

- We visualize remove(p), where p = last()



Deletion Algorithm

Algorithm remove(*p*)
{
t = *p*.element; //a temporary variable to hold the return value
(*p*.getPrev()).setNext(*p*.getNext()); // linking out *p*
(*p*.getNext()).setPrev(*p*.getPrev());
p.setPrev(**null**); // invalidating the position *p*
p.setNext(**null**);
return *t*;
}

Implementation of the Position Interface ADT (1/2)

```
public class DNode<E> implements Position<E> {
  private DNode<E> prev, next; // References to the nodes before and after
  private E element; // Element stored in this position

   /** Constructor */
  public DNode(DNode<E> newPrev, DNode<E> newNext, E elem) {
    prev = newPrev;
    next = newNext;
    element = elem; }

   // Method from interface Position
  public E element() throws InvalidPositionException {
    if ((prev == null) && (next == null)) throw new
   InvalidPositionException("Position is not in a list!");
    return element; }
```


Implementation of the Position Interface ADT (1/2)

```
 // Accessor methods

   public DNode<E> getNext() { return next; }
   public DNode<E> getPrev() { return prev; }
    // Update methods
   public void setNext(DNode<E> newNext) { next = newNext; }
   public void setPrev(DNode<E> newPrev) { prev = newPrev; }
   public void setElement(E newElement) { element = newElement; }
 }
```

Java Implementation of the Node List ADT (1/7)

```
public class NodePositionList<E> implements PositionList<E> {
    protected int numElts; // Number of elements in the list
    protected DNode<E> header, trailer; // Special sentinels
        /** Constructor that creates an empty list; O(1) time */
        public NodePositionList() {
            numElts = 0;
            header = new DNode<E>(null, null, null); // create header
            trailer = new DNode<E>(header, null, null); // create trailer
            header.setNext(trailer); // make header and trailer point to each
other
                                }
```

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Java Implementation of the Node List ADT (2/7)

```
/** Checks if position is valid for this list and converts it to DNode if it is valid;
  O(1) time */
protected DNode<E> checkPosition(Position<E> p)
  throws InvalidPositionException {
      if (p == null) throw new InvalidPositionException ("Null position passed
      to NodeList");
      if (p == header) throw new InvalidPositionException ("The header node
      is not a valid position");
      if (p == trailer) throw new InvalidPositionException ("The trailer node is
      not a valid position");
      try {
          DNode<E> temp = (DNode<E>) p;
          if ((temp.getPrev() == null) || (temp.getNext() == null))
              throw new InvalidPositionException
                ("Position does not belong to a valid NodeList");
          return temp;
        } catch (ClassCastException e) {
              throw new InvalidPositionException ("Position is of wrong type
      for this list"); } }
```

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Java Implementation of the Node List ADT (3/7)

```
/** Returns the number of elements in the list; O(1) time */

public int size() { return numElts; }

/** Returns whether the list is empty; O(1) time */

public boolean isEmpty() { return (numElts == 0); }

/** Returns the first position in the list; O(1) time */

public Position<E> first() throws EmptyListException {
  if (isEmpty()) throw new EmptyListException("List is empty");
  return header.getNext(); }
```

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Java Implementation of the Node List ADT (4/7)

```
/** Returns the position before the given one; O(1) time */
public Position<E> prev(Position<E> p) throws InvalidPositionException,
  BoundaryViolationException {
      DNode<E> v = checkPosition(p);
      DNode<E> prev = v.getPrev();
      if (prev == header) throw new BoundaryViolationException ("Cannot
  advance past the beginning of the list");
      return prev; }

/** Insert the given element before the given position, returning the new
  position; O(1) time */
public void addBefore(Position<E> p, E element) throws
  InvalidPositionException {
      DNode<E> v = checkPosition(p);
      numElts++;
      DNode<E> newNode = new DNode<E>(v.getPrev(), v, element);
      v.getPrev().setNext(newNode);
      v.setPrev(newNode); }
```

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Java Implementation of the Node List ADT (5/7)

```
/** Insert the given element at the beginning of the list, returning  the new
position; O(1) time */

public void addFirst(E element) {
  numElts++;
  DNode<E> newNode = new DNode<E>(header, header.getNext(),
element);
  header.getNext().setPrev(newNode);
  header.setNext(newNode); }
```

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Java Implementation of the Node List ADT (6/7)

```
/**Remove the given position from the list; O(1) time */
public E remove(Position<E> p) throws InvalidPositionException
 {
   DNode<E> v = checkPosition(p);
   numElts--;
   DNode<E> vPrev = v.getPrev();
   DNode<E> vNext = v.getNext();
   vPrev.setNext(vNext);
   vNext.setPrev(vPrev);
   E vElem = v.element();
   // unlink the position from the list and make it invalid
   v.setNext(null);
   v.setPrev(null);
   return vElem;
 }
```

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Java Implementation of the Node List ADT (7/7)

```
/** Replace the element at the given position with the new element and
return the old element; O(1) time */

public E set(Position<E> p, E element) throws InvalidPositionException
{
  DNode<E> v = checkPosition(p);
  E oldElt = v.element();
  v.setElement(element);
  return oldElt;
}
```


Performance

- In the implementation of the List ADT by means of a doubly linked list
  - The space used by a list with n elements is $O(n)$.
  - The space used by each position of the list is $O(1)$.
  - All the operations of the List ADT run in $O(1)$ time.
  - Operation element() of the Position ADT runs in $O(1)$ time.

Iterators

- An iterator provides a way to access the elements of an aggregate object sequentially without exposing its underlying representation.
- Extends the concept of Position by adding a traversal capability.
- An iterator consists of a sequence S, a current element in S, and a way of stepping to the next element in S and making it the current element.
- Methods of the Iterator ADT:
  - boolean hasNext(): Test whether there are elements left in the iterator.
  - object next(): Return the next element in the iterator.

Simple Iterators in JAVA (1/2)

```
public interface PositionList <E> extends Iterable <E>
 {
   // ...all the other methods of the list ADT ...
   /** Returns an iterator of all the elements in the list. */
   public Iterator<E> iterator();
 }
```


Simple Iterators in JAVA (2/2)

```
/** Returns a textual representation of a given node list */
public static <E> String toString(PositionList<E> l)
 {
   Iterator<E> it = l.iterator();
   String s = "[";
   while (it.hasNext())
     {
       s += it.next(); // implicit cast of the next element to String
       if (it.hasNext())
          s += ", ";
     }
   s += "]";
   return s;
 }
```


Implementing Iterators

- Two notions of iterator:
  - snapshot: freezes the contents of the data structure at a given time
  - dynamic: follows changes to the data structure

Snapshot

- This approach makes a "sanapshot" of a collection of elements and interates over it.
- It would involve storing the collection in a separate data structure that supports sequential access to its elements.
- Uses a cursor to keep track of the current position of the iterator.
- Creating a new iterator involves creating an iterator object that represents a cursor placed just before the first element of the collection, taking O(1) time.
- next() returns the next element, if any, and moves the cursor just past this element's position.

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Dynamic (1/3)

- This approach iterates over the data structure directly.
- No separate copy of the data structure is needed.

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Dynamic (2/3)

```
public class ElementIterator<E> implements Iterator<E>
{
  protected PositionList<E> list; // the underlying list
  protected Position<E> cursor; // the next position
   /** Creates an element iterator over the given list. */
  public ElementIterator(PositionList<E> L) {
     list = L; cursor = (list.isEmpty())? null : list.first(); }
  public boolean hasNext() { return (cursor != null); }
  public E next() throws NoSuchElementException {
    if (cursor == null) throw new NoSuchElementException("No next
 element");
    E toReturn = cursor.element();
    cursor = (cursor == list.last())? null : list.next(cursor);
    return toReturn;
 } }
```

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Dynamic (3/3)

```
 /** Returns an iterator of all the elements in the list. */
public Iterator<E> iterator() { return new ElementIterator<E>(this); }
```

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References

1. Chapter 6, Data Structures and Algorithms by Goodrich and Tamassia.

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