CS/ENGRD 2110
Object-Oriented Programming and Data Structures

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Lecture 8: Lists

List Overview

- Purpose
  - Maintain an ordered set of elements (with possible duplication)
- Common operations
  - Create a list
  - Access elements of a list sequentially
  - Insert elements into a list
  - Delete elements from a list
- Arrays
  - Random access :)
  - Fixed size: cannot grow or shrink after creation : (
- Linked Lists
  - No random access : (
  - Can grow and shrink dynamically :)

A Simple List Interface

```
public interface List<T> {
    public void insert(T element); // add to front
    public void delete(T element);
    public boolean contains(T element);
    public int size();
    public String toString();
}
```

Often also:
- Insert at last position, insert at position i
- Get first element, get last element
- Reverse
- Etc.

Generic Types

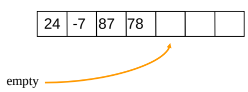
…in a Nutshell

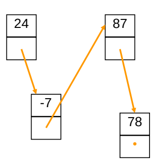
```
public interface List<E> { // E is a type variable
  void insert(E x);
  …
}

public class LinkedList<E> implements List<E> {
  void insert(E x) { … }
  …
}
```

- “List<E>” is read as “List of E”.
- To use the interface `List<E>`, supply an actual type argument, e.g., `List<Integer>`:
  - `List<Integer> list = new LinkedList<Integer>();`
- All occurrences of the formal type parameter (**E** in this case) are replaced by the actual type argument (**Integer** in this case)

List Data Structures

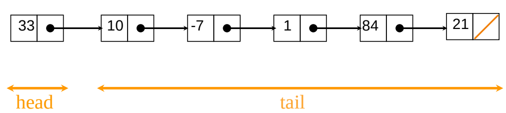
- Array
  - Must specify array size at creation
  - Insert, delete require moving elements
  - Must copy array to a larger array when it gets full
- Linked list
  - uses a sequence of linked cells
  - we will define a class ListCell from which we build lists





List Terminology

- Head = first element of the list
- Tail = rest of the list



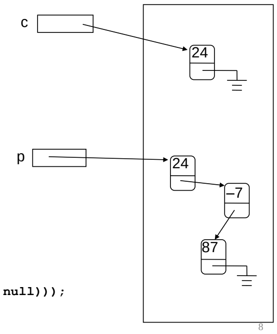
Class ListCell

```
class ListCell<T> {
   private T datum;
   private ListCell<T> next;

   public ListCell(T datum, ListCell<T> next){
      this.datum = datum;
      this.next = next;
   }

   public T getDatum() { return datum; }
   public ListCell<T> getNext() { return next; }
   public void setDatum(T obj) { datum = obj; }
   public void setNext(ListCell<T> c) { next = c; }
}
```


Building a Linked List

```
ListCell<Integer> c =
   new ListCell<Integer>(
      new Integer(24), null);
```

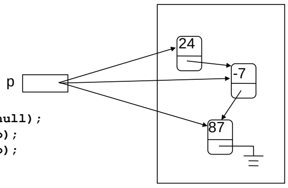
```
Integer t = new Integer(24);
Integer s = new Integer(-7);
Integer e = new Integer(87);

ListCell<Integer> p =
   new ListCell<Integer>(t,
      new ListCell<Integer>(s,
         new ListCell<Integer>(e, null)));
```



Building a Linked List (cont'd)

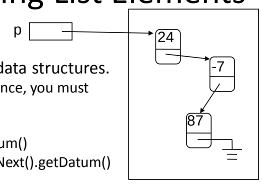
Another way:

```
Integer t = new Integer(24);
Integer s = new Integer(-7);
Integer e = new Integer(87);
//Can also use "autoboxing"

ListCell<Integer> p
  = new ListCell<Integer>(e, null);
p = new ListCell<Integer>(s, p);
p = new ListCell<Integer>(t, p);
```



Note: `p = new ListCell<Integer>(s,p);` does *not* create a circular list!

Accessing List Elements



- Linked Lists are sequential-access data structures.
  - To access contents of cell n in sequence, you must access cells 0 ... n-1
- Access
  - Accessing data in first cell: p.getDatum()
  - Accessing data in second cell: p.getNext().getDatum()
  - Accessing next field in second cell: p.getNext().getNext()
- Writing
  - Update data in first cell: p.setDatum(new Integer(53));
  - Update data in second cell: p.getNext().setDatum(new Integer(53));
  - Chop off third cell: p.getNext().setNext(null);

Access Example: Linear Search

```
// Here is another version. Why does this work?
public static boolean contains(Object x, ListCell c) {
   for (; c != null; c = c.getNext()) {
      if (c.getDatum().equals(x)) return true;
   }
   return false;
}
```

Note: we' ve left off the <Integer> for simplicity

```
// Scan list looking for x, return true if found
public static boolean contains(Object x, ListCell c) {
   for (ListCell lc = c; lc != null; lc = lc.getNext()) {
      if (lc.getDatum().equals(x)) return true;
   }
   return false;
}
```


Recursion on Lists

- Recursion can be done on lists
  - Similar to recursion on integers
- Almost always
  - Base case: empty list
  - Recursive case: Assume you can solve problem on the tail, use that in the solution for the whole list
- Many list operations can be implemented very simply by using this idea
  - Although some are easier to implement using iteration

Recursive Search

- Base cases
  - return false
  - if data in first cell equals object x, return true
- Recursive case
  - return the result of doing linear search on the tail

Recursive Search

```
public static boolean search(Object x, ListCell c) {
   if (c == null) return false;
   if (c.getDatum().equals(x)) return true;
   return search(x, c.getNext());
}
```

```
public static boolean search(Object x, ListCell c) {
   return c != null &&
      (c.getDatum().equals(x) || search(x, c.getNext()));
}
```


Reversing a List

- Given a list, create a new list with elements in reverse order
- Intuition: think of reversing a pile of coins

```
public static ListCell reverse(ListCell c) {
   ListCell rev = null;
   for (; c != null; c = c.getNext()) {
      rev = new ListCell(c.getDatum(), rev);
   }
   return rev;
}
```

- It may not be obvious how to write this recursively...

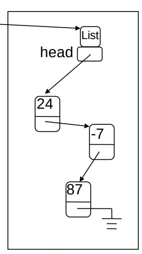
Recursive Reverse

```
public static ListCell reverse(ListCell c) {
   return reverse(c, null);
}

private static ListCell reverse(ListCell c, ListCell r) {
   if (c == null) return r;
   return reverse(c.getNext(),
                  new ListCell(c.getDatum(), r));
}
```


List with Header

- Sometimes it is preferable to have a List class distinct from the ListCell class
- The List object is like a head element that always exists even if list itself is empty

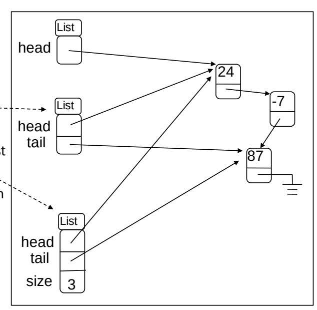
```
class List {
   protected ListCell head;
   public List(ListCell c) {
      head = c;
   }
   public ListCell getHead()
   ........
   public void setHead(ListCell c)
   ........
}
```



Heap

Variations on List with Header

- Header can also keep other info
  - Reference to last cell of list
  - Number of elements in list
  - Search/insertion/ deletion as instance methods
  - …



Special Cases to Worry About

- Empty list
  - add
  - find
  - delete
- Front of list
  - insert
- End of list
  - find
  - delete
- Lists with just one element

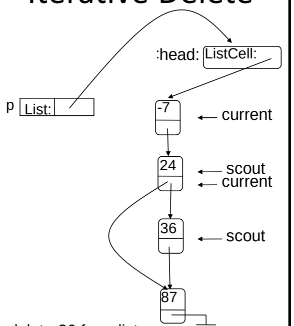
Example: Delete from a List

- Delete *first occurrence* of x from a list
- Intuitive idea of recursive code:
  - If list is empty, return null
  - If datum at head is x, return tail
  - Otherwise, return list consisting of
    - head of the list, and
    - List that results from deleting x from the tail

```
// recursive delete
public static ListCell delete(Object x, ListCell c)
{
   if (c == null) return null;
   if (c.getDatum().equals(x)) return c.getNext();
   c.setNext(delete(x, c.getNext()));
   return c;
}
```


Iterative Delete

- Two steps:
  - Locate cell that is the *predecessor* of cell to be deleted (i.e., the cell containing x)
    - Keep two cursors, *scout* and *current*
    - *scout* is always one cell ahead of *current*
    - Stop when *scout* finds cell containing x, or falls off end of list
  - If *scout* finds cell, update *next* field of *current* cell to splice out object x from list
- Note: Need special case for x in first cell



delete 36 from list

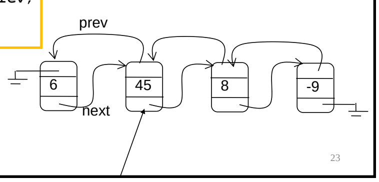
Iterative Code for Delete

```
public void delete (Object x) {
   if (head == null) return;
   if (head.getDatum().equals(x)) { //x in first cell?
      head = head.getNext();
      return;
   }
   ListCell current = head;
   ListCell scout = head.getNext();
   while ((scout != null) && !scout.getDatum().equals(x)) {
      current = scout;
      scout = scout.getNext();
   }
   if (scout != null) current.setNext(scout.getNext());
   return;
}
```


Doubly-Linked Lists

- In some applications, it is convenient to have a `ListCell` that has references to both its predecessor and its successor in the list.

```
class DLLCell {
   private Object datum;
   private DLLCell next;
   private DLLCell prev;
   …
}
```



Doubly-Linked vs Singly-Linked

- Advantages of doubly-linked over singly-linked lists
  - some things are easier – e.g., reversing a doubly-linked list can be done simply by swapping the previous and next fields of each cell
  - don't need the scout in iterative delete
- Disadvantages
  - doubly-linked lists require twice as much space
  - insert and delete take more time

Java ArrayList

- "Extensible array"
- Starts with an initial capacity = size of underlying array
- If you try to insert an element beyond the end of the array, it will allocate a new (larger) array, copy everything over invisibly
  - Appears infinitely extensible
- Advantages:
  - random access in constant time
  - dynamically extensible
- Disadvantages:
  - Allocation, copying overhead