LISTS & TREES

Lecture 9

CS2110 – Spring 2013

List Overview

2

- Purpose
  - Maintain an ordered collection 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 ☹ (Sometimes simulated using copying)
- Linked Lists
  - No random access ☹ (Sometimes random-access is “simulated” but cost is linear)
  - Can grow and shrink dynamically ☺

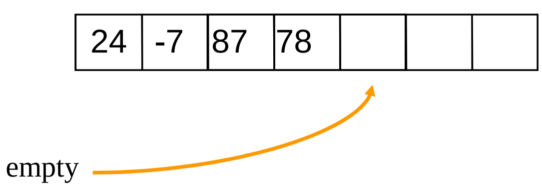
A Simple List Interface

3

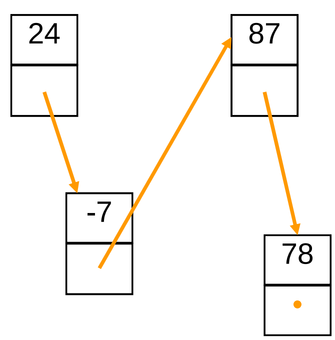
```
public interface List<T> {
   public void insert(T element);
   public void delete(T element);
   public boolean contains(T element);
   public int size();
}
```

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**



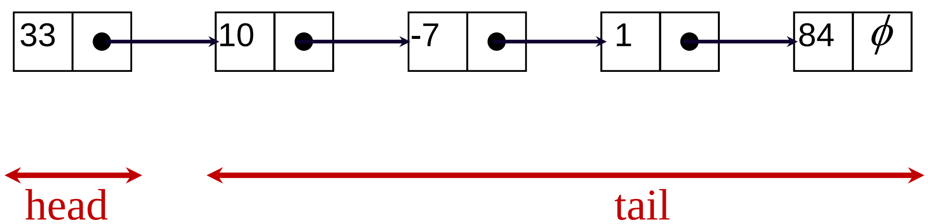
- Linked list
  - uses a sequence of linked cells
  - we will define a class ListCell from which we build lists



List Terminology

5

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

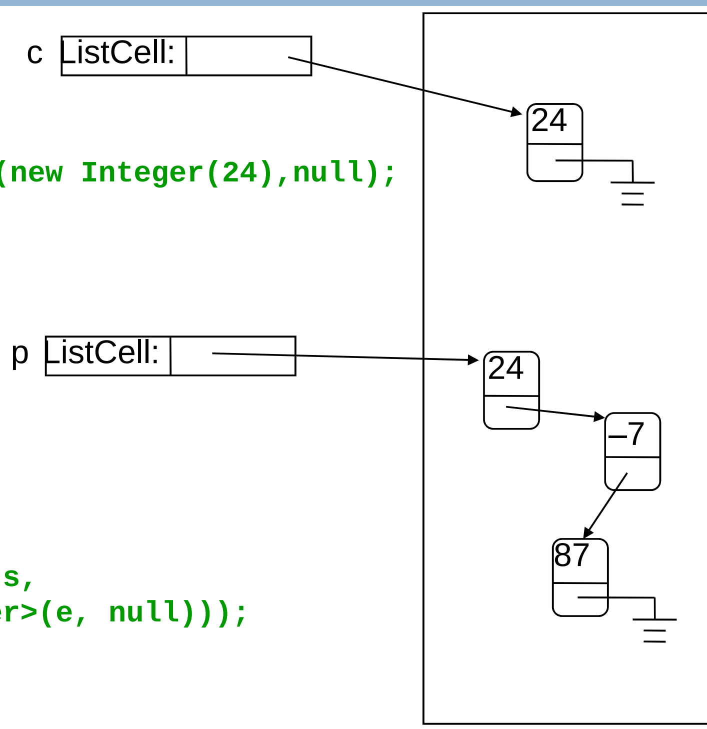


Class ListCell

Each list element "points" to the next one!
End of list: `next==null`

```
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; }
}
```

Ways of building a Linked List




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

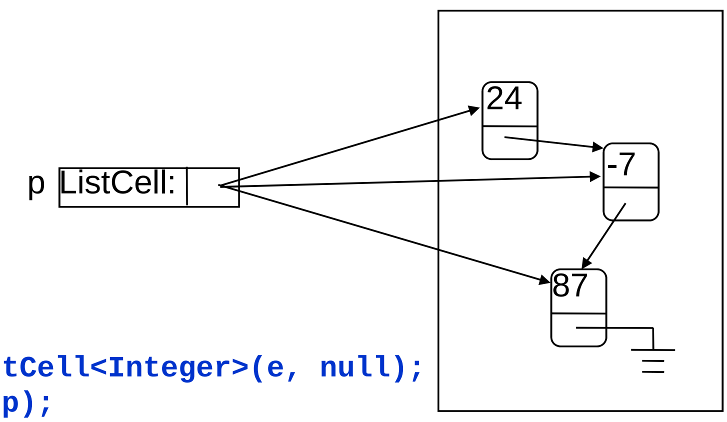
```
Integer t = new Integer(24);
Integer s = new Integer(-7);
Integer e = new Integer(87);

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

Building a Linked List (cont'd)

8

Another way:

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



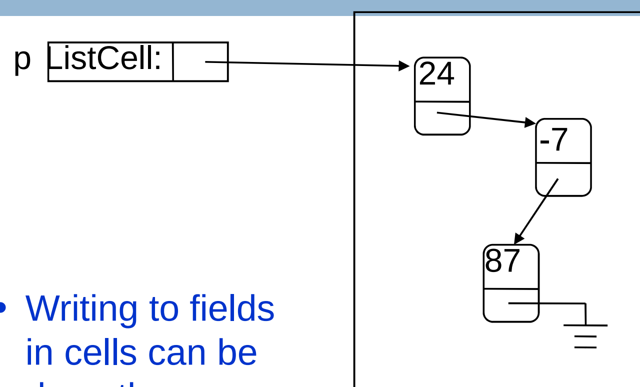

```
ListCell<Integer> p = new ListCell<Integer>(e, null);
p = new ListCell<Integer>(s, p);
p = new ListCell<Integer>(t, p);
```

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

Accessing List Elements

9

- Linked Lists are *sequential-access* data structures.
  - To access contents of cell n in sequence, you must access cells 0 ... n-1
- 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 to fields in cells can be done the same way
  - 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

10

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

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

Recursion on Lists

11

- 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

12

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

Recursive Search: Static method

13

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

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

Recursive Search: Instance method

14

```
public boolean search(T x) {
   if (datum.equals(x)) return true;
   if (next == null) return false
   return next.search(x);
}
```

```
public boolean search(T x) {
   return datum.equals(x) ||
        (next!= null && next.search(x));
}
```

Reversing a List

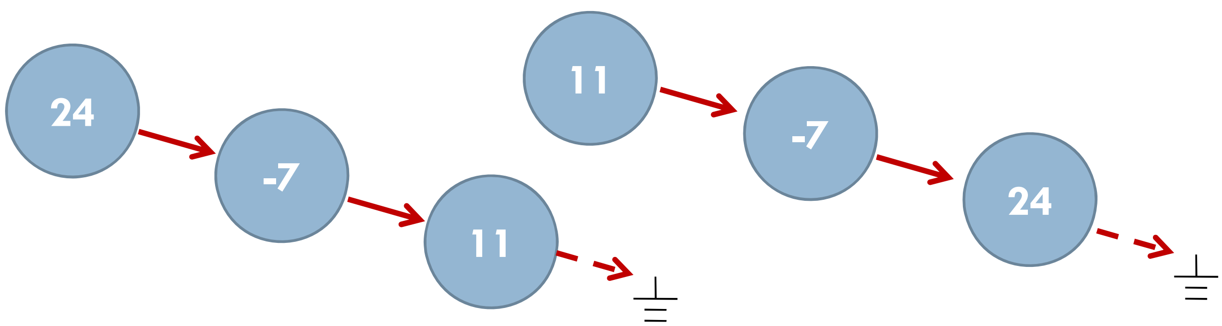
15

- 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;
   while(c != null) {
      rev = new ListCell(c.getDatum(), rev);
      c = c.getNext();
   }
   return rev;
}
```

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

Reversing a list: Animation



- Approach: One by one, remove the first element of the given list and make it the first element of "rev"
- By the time we are done, the last element from the given list will be the first element of the finished "rev"

Recursive Reverse

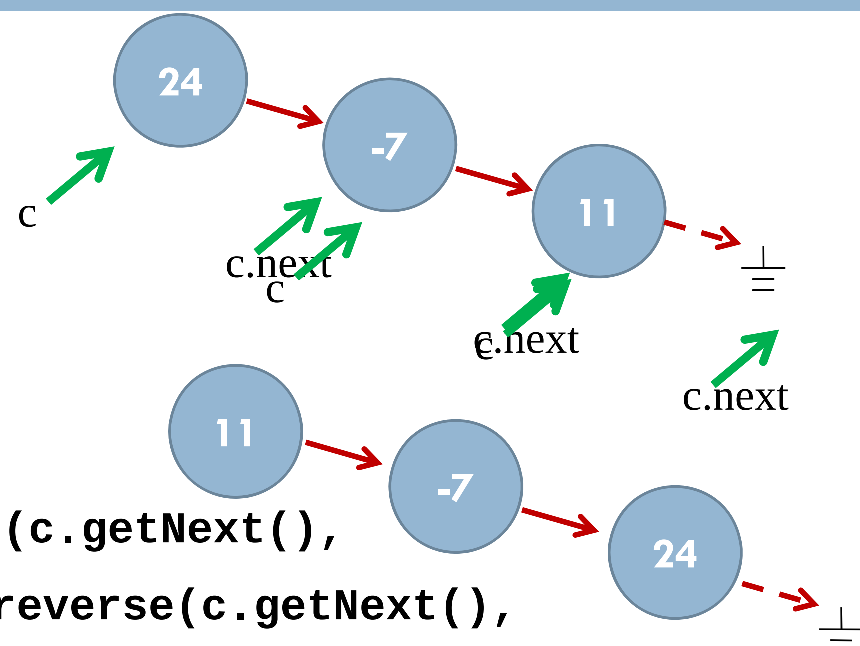
17

```
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));
}
```

- Exercise: Turn this into an instance method

Reversing a list: Animation

18



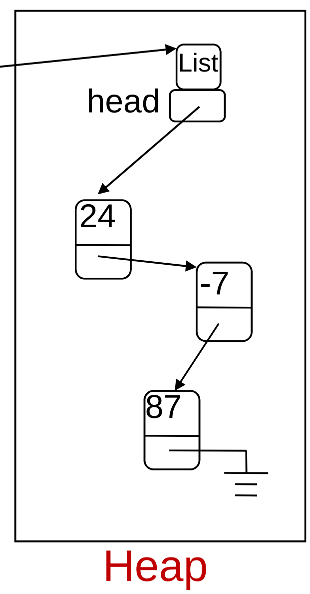

```
reverse(c.getNext(),
        reverse(c.getNext(),
                new ListCell(c.getDatum(), null));
```

List with Header

19

- 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

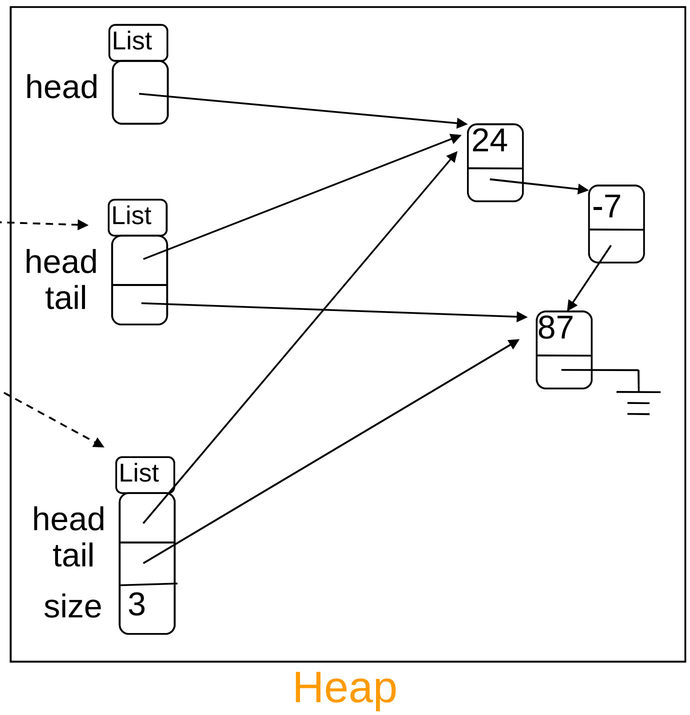
```
class List {
   protected ListCell head;
   public List(ListCell c) {
      head = c;
   }
   public ListCell getHead()
   ………
   public void setHead(ListCell c)
   ………
}
```



Variations on List with Header

20

- 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

21

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

Example: Delete from a List

22

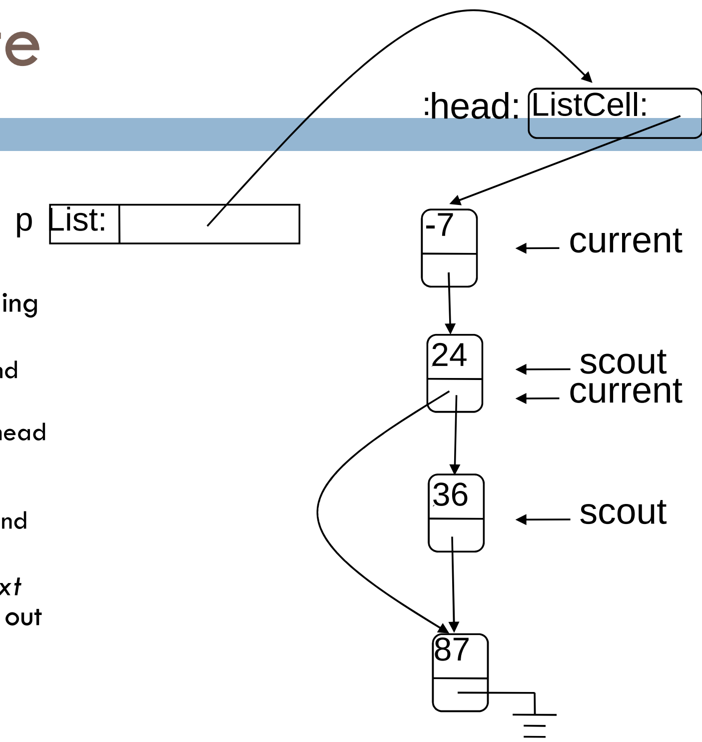
- Delete *first occurrence* of x from a list
- Intuitive idea of recursive code:
  - If list is empty, return null
  - If datum at head is x, return tail
  - Otherwise, return list consisting of

```
// 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

23

- 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

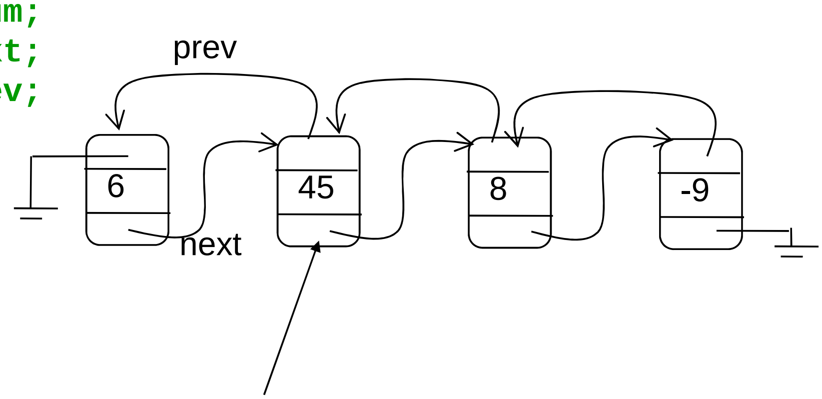
24

```
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

26

- 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 to 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