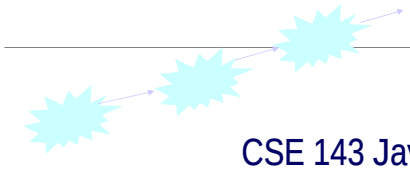


CSE 143 Java

Linked Lists

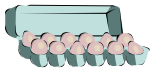
Reading: Ch. 23

Review: List Implementations

- The external interface is already defined
- Implementation goal: implement methods "efficiently"
- ArrayList approach: use an array with extra space internally
- ArrayList efficiency
  - Iterating, indexing (get & set) is fast
    Typically a one-liner
  - Adding at end is fast, except when we have to grow
  - Adding or removing in the middle is slow: requires sliding all later elements

A Different Strategy: Lists via Links

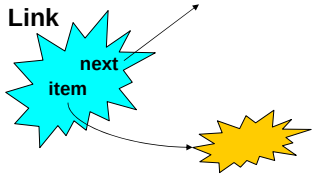
Instead of packing all elements together in an array,



create a *linked chain* of all the elements

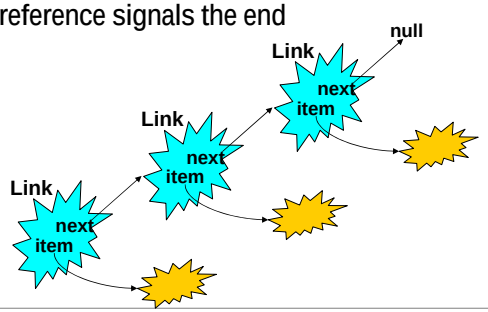
Links

- For each element in the list, create a Link object
- Each Link points to the *data item* (element) at that position, and also points to the *next* Link in the chain



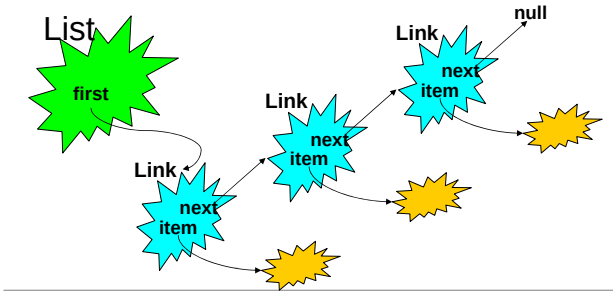
Linked Links

- Each Link points to the next
- No limit on how many can be linked
- A null reference signals the end



Linked List

- The List has a reference to the first Link
- Altogether, the list involves 3 different object types



Link Class: Data

```
/** Link for a simple list */
public class Link {
    public Object item;          // data associated with this link
    public Link next;            // next Link, or null if no next link
    //no more instance variables but
    //maybe some methods, constructors
} //end Link
```

Note 1: This class does NOT represent the chain, only one link of a chain

Note 2: "public" violates usual rules – but appropriate in this context

Note 3: The links are NOT part of the data. The data is totally unaware that it is part of a chain.

Link Constructor

```
/** Link for a simple list */
public class Link {
    public Object item;          // data associated with this link
    public Link next;            // next Link, or null if none

    /** Construct new link with given data item and next link (or null if none)
*/
    public Link(Object item, Link next) {
       this.item = item;
       this.next = next;
    }
    ...
}
```

Exercise: Add a Node (1)

- Suppose we've got a linked list containing "lion", "tiger", and "bear" in that order, with a variable pointing to the head of the list

```
Link head;          // first link in the list, or null if list is empty
```

- Draw a picture of the list

Exercise: Add a Node (2)

- Now, write the code needed to insert "wolf" between "tiger" and "bear"

Exercise: Delete a Node (1)

- Suppose we've got a list containing "IBM", "Dell", "Compaq", and "Apple" in that order

```
Link head;          // first link in the list, or null if list is empty
```

- Draw a picture

Exercise: Delete a Node (2)

- Now, write the code needed to delete "Compaq" from the list

LinkedList Data

```
/** Simple version of LinkedList for CSE143 lecture example */
public class SimpleLinkedList implements List {
    // instance variables
    private Link first;             // first link in the list, or null if list is empty
    ...

}
```

LinkedList Data & Constructor

```
/** Simple version of LinkedList for CSE143 lecture example */
public class SimpleLinkedList implements List {
    // instance variables
    private Link first;             // first link in the list, or null if list is empty
    ...

    /** construct new empty list */
    public SimpleLinkedList( ) {
       first = null;                // no links yet!
    }

    ...
```

List Interface (review)

- Operations to implement:

```
int size( )
boolean isEmpty( )
boolean add(Object o)
boolean addAll(Collection other)
void clear( )
Object get(int pos)
boolean set(int pos, Object o)
int indexOf(Object o)
boolean contains(Object o)
Object remove(int pos)
boolean remove(Object o)
boolean add(int pos, Object o)
Iterator iterator( )
```


Method *add* (First Try)

```
public boolean add(Object o) {
    // create new link and place at end of list:
    Link newLink = new Link(o, null);
    // find last link in existing chain: it's the one whose next link is null:
    Link p = first;
    while (p.next  !=  null) {
        p = p.next;
    }
    // found last link; now add the new link after it:
    p.next = newLink;
    return true;   // we changed the list => return true
}
```

Draw the Picture

- Client code:

```
LinkedList vertexes = new SimpleLinkedList();
Point2D p1 = new Point2D.Double(100.0, 50.0);
Point2D p2 = new Point2D.Double( 250, 310);
Point2D p3 = new Point2D.Double(90, 350.0);
vextexes.add(p1);
vertexes.add(p2);
vertexes.add(p3);
vertexes.add(p1);
```


Problems with naïve *add* method

- Inefficient: requires traversal of entire list to get to the end
  - One loop iteration per link
  - Gets slower as list gets longer
  - Solution??
- Buggy: fails when adding first link to an empty list
  - Check the code: where does it fail?
  - Solution??

Improvements to naïve *add* method

- Inefficient: requires traversal of entire list to get to the end
  - A solution: Change LinkedList to keep a pointer to *last* link as well as the *first*
- Buggy: fails when adding first link to an empty list
  - A solution: check for this case and execute special code
- Q: "Couldn't we ....?" Answer: "probably". There are many ways link lists could be implemented

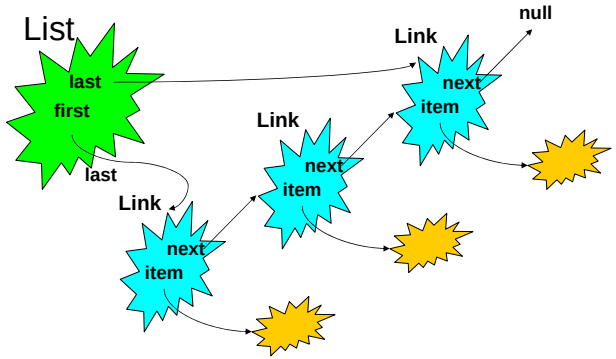
List Data & Constructor (revised)

```
public class SimpleLinkedList implements List {
    // instance variables
    private Link first;          // first link in the list, or null if list is empty
    private Link last;           // last link in the list, or null if list is empty
    ...

    /** construct new empty list */
    public SimpleLinkedList( ) {
       first = null;             // no links yet!
       last = null;              // no links yet!
    }

    ...
```

Link List with last



Method *add* (Final Version)

```
public boolean add(Object o) {
    // create new link to place at end of list:
    Link newLink = new Link(o, null);
    // check if adding the first link
    if (first == null) {
        // we're adding the first link
        first = newLink;
    } else {
        // we have some existing links; add the new link after the old last link
        last.next = newLink;
    }
    // update the last link
    last = newLink;
    return true;   // we changed the list => return true
}
```


Method *size( )*

- First try it with this restriction: you can't add or redefine instance variables
- Hint: count the number of links in the chain

```
/** Return size of this list */
public int size( ) {
    int count = 0;




    return count;
}
```

- Critique?

Method *size* (faster)

- Add an instance variable to the list class

```
int numLinks;          // number of links in this list
```

- Add to constructor:

```
numLinks = 0;
```

- Add to method *add*:

```
numLinks ++;
```

- Method *size*

```
/** Return size of this list */
public int size( ) {
    return numLinks;
}
```

- Critique?

clear

- Simpler than with arrays or not?

```
/** Clear this list */
public void clear( ) {
    first = null;
    last = null;
    numLinks = 0;
}
```

- No need to "null out" the elements themselves
  - Garbage Collector will reclaim the Link objects automatically

    (Some GCs might reclaim the objects quicker if we did null out the links, but good ones shouldn't need this)

get

```
/** Return object at position pos of this list. 0 <= pos < size, else IndexOOBExn */
public Object get(int pos) {
    if (pos < 0 || pos >= numLinks) {
      throw new IndexOutOfBoundsException( );
    }
    // search for pos'th link
    Link p = first;
    for (int k = 0; k < pos; k++) {
      p = p.next;
    }
    // found it; now return the element in this link
    return p.item;
}
```

- Critique?
- DO try this at home. Try "set" too

add and *remove* at given position

- Observation: to add a link at position k, we need to change the next pointer of the link at position k-1

- Observation: to remove a link at position k, we need to change the next pointer of the link at position k-1

Helper for *add* and *remove*

- Possible helper method: get link given its position

```
// Return the link at position pos
// precondition (unchecked): 0 <= pos < size
private Link getLinkAtPos(int pos) {
    Link p = first;
    for (int k = 0; k < pos; k++) {
      p = p.next;
    }
    return p;
}
```

  - Use this in get, too
  - How is this different from the get(pos) method of the List?

remove(pos): Study at Home!

```
/** Remove the object at position pos from this list. 0 <= pos < size, else
IndexOutOfBoundsException */
public Object remove(int pos) {
    if (pos < 0 || pos >= numLinks) { throw new IndexOutOfBoundsException( ); }
    Object removedElem;
    if (pos == 0) {
        removedElem = first.item;          // remember removed item, to return it
        first = first.next;                // remove first link
        if (first == null) { last = null; }  // update last, if needed
    } else {
        Link prev = getLinkAtPos(pos-1);   // find link before one to remove
        removedElem = prev.next.item;      // remember removed item, to return it
        prev.next = prev.next.next;        // splice out link to remove
        if (prev.next == null) { last = prev; }  // update last, if needed
    }
    numLinks --;                           // remember to decrement the size!
    return removedElem;
}
```


add(pos): Study at Home!

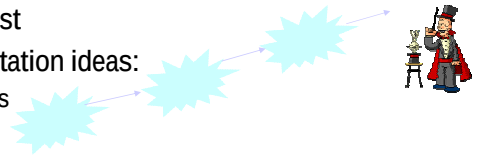
```
/** Add object o at position pos in this list. 0 <= pos <= size, else IndexOOBExn */
public boolean add(int pos, Object o) {
    if (pos < 0 || pos >= numLinks) { throw new IndexOutOfBoundsException( ); }
    if (pos == 0) {
        first = new Link(o, first);          // insert new link in front of the chain
        if (last == null) { last = first; }  // update last, if needed
    } else {
        Link prev = getLinkAtPos(pos-1);     // find link before one to insert
        prev.next = new Link(o, prev.next);  // splice in new link between prev &
                                             //   prev.next
        if (last == prev) { last = prev.next; }  // update last, if needed
    }
    numLinks ++;                             // remember to increment the size
    return true;
}
```


Implementing *iterator( )*

- To implement an iterator, could do the same thing as with SimpleArrayLists: return an instance of SimpleListIterator
- Recall: SimpleListIterator tracks the List and the position (index) of the next item to return
  - How efficient is this for LinkedLists?
  - Can we do better?

Summary

- SimpleLinkedList presents same illusion to its clients as SimpleArrayList
- Key implementation ideas:
  - a chain of links



- Different efficiency trade-offs than SimpleArrayList
  - must search to find positions, but can easily insert & remove without growing or sliding
  - get, set a lot slower
  - add, remove faster (particularly at the front): no sliding required