CS 310: Array-y vs Linky Lists

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Week 4-2

Logistics

Reading

- Weiss Ch 17 Linked Lists
- Pay attention to notion of Iterators

Goals

- Linked List implementation
- Iterators

Practice problems

- Write your own doubly linked list with List operations `add(x)` `add(i,x)` `remove(i)` `get(i)` `set(i,x)`
- 17.9: Implement `LinkedList.removeAll(T x)`, get rid of all `equals(x)`
- 17.20: Augment `ListIterator` to have `add(T x)` for positional adding

Quick Review Questions

Method `xFer(double x[])` takes an array of size N and completes after $10 + 4N + \frac{1}{2}N^2 - \log_2(N)$ steps.

- What is the big-O runtime complexity of `xfer()`?

For an `ArrayList` with N elements...

- What is the runtime complexity of `get(i)`?
- What is the runtime complexity of `remove(i)`?
- What is the memory overhead of `remove(i)`?
- What is the runtime complexity of `add(x)`?
- What is the memory overhead of `add(x)`?

Stacks and Queues

- What are the basic operations of a Stack?
- Of a Queue?
- Describe two fundamental ways to implement a Stacks/Queues. Mention what fields are required in each

The Notion of a List

```
package java.util;

public interface List<E> extends Collection<E>
```

> *An ordered collection (also known as a sequence). The user of this interface has precise control over where in the list each element is inserted. The user can access elements by their integer index (position in the list), and search for elements in the list.*

Can implement this two ways

- Based on contiguous memory (ArrayList)
- Based on linked nodes of memory (LinkedList)

Choice leads to consequences for operations complexity

Links Aren't Just for Queues

- Recall `ListQueue` - built on `Node`
- Slight tweaks enable general `List` data structure with `get(i)/set(i,x)/add(x)` capabilities
- Node fields `head` (front) and `tail` (back)

Name	Description	Big-O Runtime
`add(x)`	Add `x` to the end	
`addFront(x)`	Add `x` at the 0th index	
`get(i)`	Retrieve element `i`	
`set(i,x)`	Set element `i` to `x`	
`insert(i,x)`	Add `x` at position `i`	
`remove(i)`	Remove element `i`	

- How are these operations implemented? Pseudocode or Java
- What are the runtime complexities of each?
- How are the operation complexities of `LinkedList` different from `ArrayList`?

Exercise: Complexity of Access Forward/Backward

Print elements front to back

```
class ArrayList/LinkedList{
  public void printAll(){...}
}
```

- `ArrayList` implementation
- `SinglyLinkedList` implementation
- Make both $O(N)$

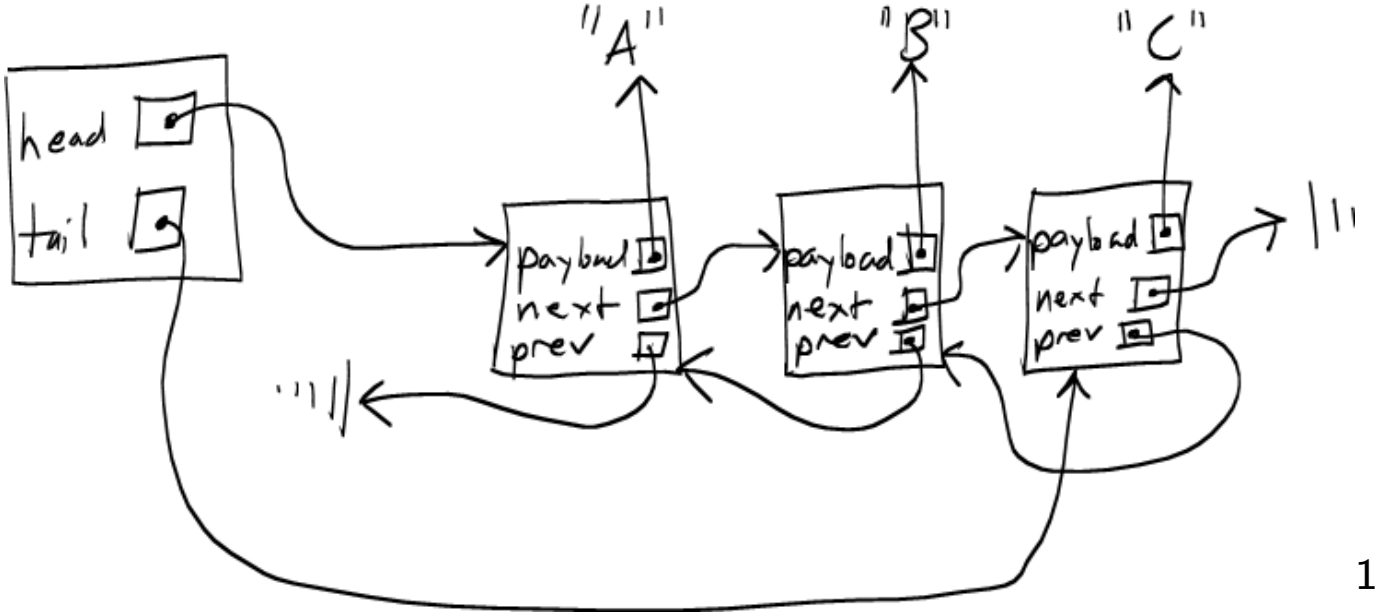
Print elements back to front

```
class ArrayList/LinkedList{
  public void printAllReverse(){...}
}
```

- `ArrayList` implementation
- `SinglyLinkedList` implementation (!)
- Can both be $O(N)$?

Double Your Fun

- Singly linked nodes: only `next` field
  - `Node n = new Node(data,next);`
- Doubly linked also has `previous` field as well
  - `Node n = new Node(data, previous, next);`



[1]

How about `printAllReverse()` now

[1] Source: David H. Hovemeyer's notes

To Header or Not to Header

- Some linked list implementations use auxiliary 'header' and 'tailer' nodes
- Contain no data, there to simplify code, no `null` cases
- Draw pictures to understand these
- Weiss uses header/tailer nodes
- Consider code below for `add(x)` to the back of a linked list

No Header

```
public void add(T x){
  if(empty()){
    head =
      new Node(x,null,null);
    tail = head;
  }
  else{
    tail.next =
      new Node(x,tail,null);
    tail = tail.next;
  }
}
```

With Header/Tailer

```
public void add(T x){
  Node newLast =
    new Node(x,tail.previous,
                tail);
  tail.previous.next = newLast;
  tail.previous =      newLast;
}
```

Exercise: Doubly Linked add(i,x) / insert(i,x)

- Insert x at position i in list
- List is doubly linked, headed
- Both head and tail point to ever-present dummy nodes

```
class LinkedList<T>{
  static class Node<X>{
    X data; Node<X> next, prev;
    public Node(X d, Node<X> p, Node<X> n){
      this.data=d; this.next=n; this.prev=p;
    }
  }
  private Node<T> headNode, tailNode;   // Always present, contains no data
  private int size;                     // Number of elements in the list
  // Constructor to create an empty list
  public LinkedList( ){
    this.headNode = new Node<T>(null,null,null);
    this.tailNode = new Node<T>(null,headNode,null);
    this.headNode.next = tailNode;
    this.size = 0;
  }
  // Add x at position i, 0 <= i <= size()
  public void add(int i, T x){
    // WRITE ME, don't use iterators
  }
}
```

A Problem

Recall

- `ArrayList.get(i)` : $O(1)$
- `LinkedList.get(i)` : $O(n)$

Trouble

```
List<Integers> l = ...;
int sum = 0;
for(int i=0; i<l.size(); i++){
  sum +=  l.get(i);
}
```

What is the complexity of the loop?

Peeking Inside with Iterators

Arrays are simple

- `get`/`set` anything in $O(1)$
- `add`/`remove` is obvious
- Very clear how data is laid out

Just about every other data structure is less straight-forward

- Getting/setting nontrivial
- Must preserve some internal structure - control access
- Element-by-element traversal needs to be done carefully

These qualities give rise to iterators

- A view of a data structure at a specific position
- Allow movement through structure, access to elements

Iterators

Give access to a position in a Collection

ListIterator Interface

```
public interface ListIterator<T>{
  // Can the iterator be moved?
  public boolean hasNext( );
  public boolean hasPrevious( );

  // Move the iterator
  public T next( );
  public T previous( );

  // Modify the container
  public void add(x);
  public void remove( );
}
```

Semantics

- Collection creates/provides an iterator
- Use `next()/previous()` to move
- `next()/previous()` returns element "moved over"
- `remove()` removes element that was returned from last `next()/previous()`
- Illegal to remove w/o first calling `next()/previous()`
- `add(x)` before whatever `next()` would return

Iterators are In Between Elements

List Iterators have slightly complex semantics: *between* list elements

Next/Previous

```
LL l = new LL([A, B, C, D])
itr = l.iterator()
                [ A B C D ]
                 ^
itr.next()      [ A B C D ]
A                  ^
itr.next()      [ A B C D ]
B                    ^
itr.previous() [ A B C D ]
B                  ^
itr.previous() [ A B C D ]
A                ^
itr.previous()
--> NoSuchElementException
                [ A B C D ]
                 ^
```

Add/Remove

```
LL l = new LL([A, B, C, D])
itr = l.iterator()
                [ A B C D]
                 ^
itr.add(X)      [ X A B C D ]
                   ^
itr.next()      [ X A B C D ]
A                    ^
itr.next()      [ X A B C D ]
B                      ^
itr.remove()    [ X A C D ]
                     ^
itr.remove()    [ X A C D ]
--> ERROR            ^
itr.previous() [ X A C D ]
A                  ^
itr.add(Y)      [ X Y A C D ]
                       ^
```

Common Patterns using Iterators / Iterable

```
// Remove elements from List l using an iterator
public static void removeEqual(List<T> l, T x){
  Iterator<T> it=l.iterator();  // get an iterator
  while(it.hasNext()){          // while it can move forward
    T y = it.next();            // grab an element
    if(x.equals(y)){            // if it should be removed
      it.remove();              // ask the iterator to remove it
    }
  }
}

// Count elements in y equal to x using for-each loop
public static int countEqual(List<T> l, T x){
  int count=0;
  for(T y : l){                 // iterator/hasNext() done
    if(x.equals(y)){            // automatically in a for-each
      count++;
    }
  }
  return count;
}
```

Exercise: Draw the Final List

```
LL l = new LL([A, B, C, D])
iter = l.iterator()
iter.next()
iter.next()
iter.add("X")
iter.previous()
iter.add("Y")
iter.next()
iter.next()
iter.remove()
iter.next()
iter.add("W")
iter.previous()
iter.remove()
```

Draw the final list as doubly linked nodes. Include the position of `iter`.

What would you do?

```
// l = [A, B, C, D];
it1 = l.iterator().next().next();
it2 = l.iterator().next();
// l = [ A B C D ]
//           1
//         2
it1.remove();
it2.next(); // ??
```

Where should `it2` be now?

- Determine viable possibilities
- Explore what Java actually does

ConcurrentModificationException

Java's premise: Danger!

```
it1 = l.iterator();
it2 = l.iterator();
it1.remove();
it2.next(); // Error
```

Doesn't try to coordinate multiple iterators changing a collection

- Multiple iterators easy for reading/viewing
- Very difficult to coordinate modifications
- A generally recurring pattern in CS: *multiple simultaneous actors are a pain in the @$$*
- Detect multiple concurrent modifications using `modCount` field, see Weiss

Nested Namespaces

- Java restriction: *1 public class per file*
- Sometimes this is bothersome
- Group of related classes
  - One external public class
  - Uses some internal classes
  - Internal classes not for public consumption
  - List, Node, Iterator
- Endow internal classes with access to containing class
- Analogy: `Body`, `Body.Heart`, `Body.Stomach`, `Body.Brain`
- Makes programming more convenient

Nested and Inner Classes

Straight from the official docs[2]

```
class OuterClass {
  ...
  static class StaticNestedClass {
    ...
  }
  class InnerClass {
    ...
  }
}
```

Both nested/inner classes

- Put multiple classes in a single file
- Give access to namespace of `OuterClass`
- Have access to private methods of `OuterClass`

[2] Courtesy of Oracle

Some Textbook Classes

Singly linked node, list, iterator (17.1-2)

All classes separate

`weiss.nonstandard.LinkedList`
`weiss.nonstandard.ListNode`
`weiss.nonstandard.LinkedListIterator`

Interfaces, `ListIterator extends Iterator`

Implemented by `ArrayList/LinkedList`

`weiss.util.List`
`weiss.util.Iterator`
`weiss.util.ListIterator`

Doubly Linked list (17.3-5)

`weiss.util.LinkedList`
`weiss.util.LinkedList.LinkedListIterator (inner, non-static)`
`weiss.util.LinkedList.Node (nested, static)`

Wrap-up

Lists

- ArrayList and LinkedList
- Both allow sequential access of element `i`
- Both often provide iterators (see Weiss's implementation of ArrayLists with Iterators)
- Have markedly different data layout, consequences for performance

Practice problems for home

- Write your own doubly linked list with List operations `add(x)` `add(i,x)` `remove(i)` `get(i)` `set(i,x)`
- 17.9: Implement `LinkedList.removeAll(T x)`, get rid of all `equals(x)`
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