CSE 143 Java

List Implementation via Arrays

Reading: N&H Ch. 22

Implementing a List in Java

- Two implementation approaches are most commonly used for simple lists:
  - List via Arrays
  - Linked list
- Java Interface List
  - concrete classes ArrayList, LinkedList
  - same methods, different internals
  - List in turn extends (implements) Collection
- Our current activities:
  - Lectures on list implementations, in gruesome detail
    SimpleArrayList is a class we develop as an example
  - Projects in which lists are used

List Interface (review)

```
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( )
```


Just an Illusion?

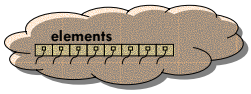
- Key concept: *external view* (the **abstraction** visible to clients) vs. *internal view* (the **implementation**)
- SimpleArrayList may present an illusion to its clients
  - Appears to be a simple, unbounded list of elements
  - Actually may be a complicated internal structure
- The programmer as illusionist...

- This is what abstraction is all about

Using an Array to Implement a List

- Idea: store the list elements in an array instance variable

```
// Simple version of ArrayList for CSE143 lecture example
public class SimpleArrayList implements List {
    /** variable to hold all elements of the list*/
    private Object[ ] elements;
    ...
}
```



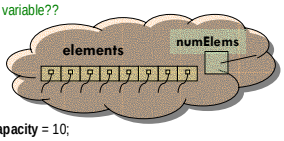
- Issues:
  - How big to make the array?
  - Why make the array of type Object[ ]? Pros, cons?
  - Algorithms for adding and deleting elements (add and remove methods)
  - Later: performance analysis of the algorithms

Space Management: Size vs. Capacity

- Idea: allocate extra space in the array,
  - possibly more than is actually needed at a given time
  - *size*: the number of elements in the list, from the client's view
  - *capacity*: the length of the array (the maximum size)
  - invariant: 0 <= *size* <= *capacity*
- When list object created, create an array of some initial maximum capacity
  - What happens if we try to add more elements than the initial capacity? see later…

List Representation

```
public class SimpleArrayList implements List {
    // instance variables
    private Object[ ] elements;      // elements stored in elements[0..numElems-1]
    private int numElems;            // size: # of elements currently in the list
    // capacity ?? Why no capacity variable??
```




```
  // default capacity
    private static final int defaultCapacity = 10;
    ...
}
```

Review: what is the "static final"?

Constructors

- We'll provide two constructors:

```
/** Construct new list with specified capacity */
public SimpleArrayList(int capacity) {
    this.elements = new Object[capacity];
    this.numElems = 0;
}

/** Construct new list with default capacity */
public SimpleArrayList( ) {
    this(defaultCapacity);
}
```

- Review: this(…)
  - means what?
  - can be used where?

size, *isEmpty*: Signatures

- size:

```
/** Return size of this list */
public int size( ) {


}
```

- isEmpty:

```
/** Return whether the list is empty (has no elements) */
public boolean isEmpty( ) {


}
```


size, *isEmpty*: Code

- size:

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

- isEmpty:

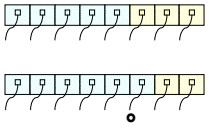
```
/** Return whether the list is empty (has no elements) */
public boolean isEmpty( ) {
    return this.size( ) == 0;  //OR return (this.numElems == 0);
}
```

  - Each choice has pros and cons: what are they?

Method *add*: simple version

- Assuming there is unused capacity ...

```
/** Add object o to the end of this list.
    @return truen iff the object was added successfully.
      This implementation always returns true. */
public boolean add(Object o) {
```



```
    return true;
}
```


Method *add*: simple version

- Assuming there is unused capacity ...

```
/** Add object o to the end of this list
    @return true, since list is always changed by an add */
public boolean add(Object o) {
    if (this.numElems < this.elements.length) {
        this.elements[this.numElems] = o;
        this.numElems ++;
    } else {
        // yuck; what can we do here?  here's a temporary measure....
        throw new RuntimeException("list capacity exceeded");
    }
    return true;
}
```

- addAll(array or list) left as an exercise – try it at home!
  - Could your solution be put in an abstract superclass?

Method *clear*: Signature

```
/** Empty this list */
public void clear( ) {




}
```

- Can be done by adding just one line of code!
- "Can be", but "should be"?

clear: Code

- Logically, all we need to do is set this.numElems = 0
- But it's good practice to null out all of the object references in the list. Why?

```
/** Empty this list */
public void clear( ) {
    for (int k = 0; k < this.numElems; k++) { //optional
        this.elements[k] = null;
    }
    this.numElems = 0;
}
```


Method *get*

```
/** Return object at position pos of this list
The list is unchanged
*/
public Object get(int pos) {
        return this.elements[pos];
}
```

- Anything wrong with this?

  Hint: what are the preconditions?

A Better *get* Implementation

- We want to catch out-of-bounds arguments, including ones that reference unused parts of array elements

```
/** Return object at position pos of this list.
   0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public Object get(int pos) {
    if (pos < 0  ||  pos >= this.numElems) {
        throw new IndexOutOfBoundsException( );
    }
    return this.elements[pos];
}
```

- Question: is a "throws" clause required?
- Exercise: write out the preconditions more fully
- Exercise: specify and implement the *set* method

Method *indexOf*

- Sequential search for first "equal" object

```
/** return first location of object o in this list if found, otherwise return –1 */
public int indexOf(Object o) {
    for (int k = 0; k < this.size( ); k++) {
        Object elem = this.get(k);
        if (elem.equals(o)) {
            // found item; return its position
            return k;
        }
    }
    // item not found
    return -1;
}
```

- Exercise: write postconditions
- Could this be implemented in an abstract superclass?

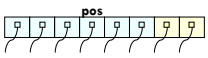
Method *contains*

```
/** return true if this list contains object o, otherwise false */
public boolean contains(Object o) {
    // just use indexOf
    return this.indexOf(o)  !=  -1;
}
```

- As usual, an alternate, impementation-dependent version is possible
- Exercise: define "this list contains object o" more rigorously

remove(pos): Specification

```
/** Remove the object at position pos from this list.  Return the removed element.
    0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public Object remove(int pos) {
...
    return removedElem;
}
```



- Postconditions: quite a bit more complicated this time...
  - Try writing them out!
- Key observation for implementation:
  - we need to compact the array after removing something in the middle; slide all later elements left one position

remove(pos): Code

```
/** Remove the object at position pos from this list.  Return the removed element.
    0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public Object remove(int pos) {
    if (pos < 0 || pos >= this.numElems) {
        throw new IndexOutOfBoundsException( );
    }
    Object removedElem = this.elements[pos];
    for (int k = pos+1; k < this.numElems; k++) {
        this.elements[k-1] = this.elements[k];      // slide k'th element left by one index
    }
    this.numElems[this.numElems-1] = null;      // erase extra ref. to last element, for GC
    this.numElems--;
    return removedElem;
}
```

remove(Object)

```
/** Remove the first occurrence of object o from this list, if present.
    @return true if list altered, false if not */
public boolean remove(Object o) {
    int pos = indexOf(o);
    if (pos != -1) {
        remove(pos);
        return true;
    } else {
        return false;
    }
}
```

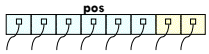
- Pre- and postconditions are not quite the same as remove(pos)

add Object at position

```
/** Add object o at position pos in this list.  List changes, so return true
    0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public boolean add(int pos, Object o) {

    ...
```

- Key implementation idea:
  - we need to make space in the middle; slide all later elements right one position
- Pre- and postconditions?



add(pos, o): Code

```
/** Add object o at position pos in this list.  List changes, so return true
    0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public boolean add(int pos, Object o) {
    if (pos < 0 || pos >= this.numElems) {
        throw new IndexOutOfBoundsException( );
    }
    if (this.numElems >= this.elements.length) {
        // yuck; what can we do here?  here's a temporary measure....
        throw new RuntimeException("list capacity exceeded");
    }
    ... continued on next slide ...
```


add(pos, o) (continued)

```
    ...
    //preconditions have been met
    // first create a space
    for (int k = this.numElems - 1; k >= pos; k --) {    // must count down!
        this.elements[k+1] = this.elements[k];// slide k'th element right by one index
    }
    this.numElems ++;

    // now store object in the space opened up
    this.elements[pos] = o;          // erase extra ref. to last element, for GC
    return true;
}
```

add Revisited – Dynamic Allocation

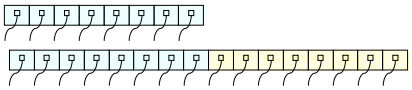
- Our original version of add checked for the case when adding an object to a list with no spare capacity
  - But did not handle it gracefully: threw an exception
- Better handling: "grow" the array
- Problem: Java arrays are fixed size – can't grow or shrink
- Solution: Make a new array of needed size
- This is called *dynamic allocation*

Dynamic Allocation Algorithm

Algorithm:

1. **allocate** a new array with larger capacity,
2. **copy** the elements from the old array to the new array, and
3. **replace** the old array with the new one

   i.e., make the array name refer to the new array



- Issue: How big should the new array be?

Method *add* with Dynamic Allocation

- Following implementation has the dynamic allocation buried out of sight...

```
/** Add object o to the end of this list
    @return true, since list is always changed by an add */
public boolean add(Object o) {
    this.ensureExtraCapacity(1);
    this.elements[this.numElems] = o;
    this.numElems ++;
    return true;
}

/** Ensure that elements has at least extraCapacity free space,
    growing elements if needed */
private void ensureExtraCapacity(int extraCapacity) {
    ... magic here ...
}
```


ensureExtraCapacity

```
/** Ensure that elements[] has at least extraCapacity free space,
    growing elements[] if needed */
private void ensureExtraCapacity(int extraCapacity) {
    if (this.numElems + extraCapacity > this.elements.length) {
        // we need to grow the array
        int newCapacity = this.elements.length * 2 + extraCapacity;
        Object[] newElements = new Object[newCapacity];
        for (int k = 0; k < this.numElems; k++) {
            newElements[k] = this.elements[k];  //copying old to new
        }
        this.elements = newElements;
    }
}
```

- Note: this is *ensure* extra capacity, not add extra capacity.
- Pre- and Post- conditions?

Method *iterator*

- Collection interface specifies a method *iterator( )* that returns a suitable Iterator for objects of that class
  - Key Iterator methods: boolean hasNext( ), Object next( )
  - Method remove( ) is optional for Iterator in general, but expected to be implemented for lists. [left as an exercise]
- Idea: Iterator object holds...
  - a reference to the list it is traversing and
  - the current position in that list.
- Can be used for any List, not just ArrayList!
- Except for remove( ), iterator operations should never modify the underlying list

Method *iterator*

- In class SimpleArrayList

```
/** Return a suitable iterator for this list */
public Iterator iterator( ) {
    return new SimpleListIterator(this);
}
```


Class SimpleListIterator (1)

```
/** Iterator helper class for lists */
class SimpleListIterator implements Iterator {
    // instance variables
    private List list;              // the list we are traversing
    private int nextItemPos;        // position of next element to visit (if any left)
    // invariant: 0 <= nextItemPos <= list.size( )

    /** construct iterator object */
    public SimpleListIterator(List list) {
       this.list = list;
       this.nextItemPos = 0;
    }

    ...
```


Class SimpleListIterator (2)

```
/** return true if more objects remain in this iteration */
public boolean hasNext( ) {
    return this.nextItemPos < this.list.size( );
}
/** return next item in this iteration and advance.
Note: changes the state of the Iterator but not of the List
   @throws NoSuchElementException if iteration has no more elements */
public Object next( ) {
    if ( ! hasNext( ) ) {
       throw new NoSuchElementException( );
    }
    Object result = this.list.get(this.nextItemPos);
    this.nextItemPos ++;
    return result;
}
```

Design Question

- Why create a separate Iterator object?
- Couldn't the list itself have..
  - ...operations for iteration?
    hasNext( )
    next( )
    reset( ) //start iterating again from the beginning
  - ...private instance variable for nextPos?

Summary

- SimpleArrayList presents an illusion to its clients
  - Appears to be a simple, unbounded list of elements
  - Actually a more complicated array-based implementation
- Key implementation ideas:
  - capacity vs. size/numElems
  - sliding elements to implement (inserting) add and remove
  - growing to increase capacity when needed
    growing is transparent to client
- Caution: Frequent sliding and growing is likely to be expensive....