CSC 143 Java

List Implementation via Arrays

Reading: 13

Implementing a List in Java

- Two implementation approaches are most commonly used for simple lists:
  - List via Arrays
  - Linked list
- Java Interface List<E>
  - concrete classes ArrayList, LinkedList
  - same methods, different internals
  - List in turn extends (implements) Collection<E>
- 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<E> Interface (review)

```
int size( )
boolean isEmpty( )
boolean add( E o)
boolean addAll( Collection<E> other) // Not exactly the signature, but…
void clear( )
E get(int pos)
boolean set( int pos, E o)
int indexOf( Object o)
boolean contains( Object o)
E remove( int pos)
boolean remove( Object o)
boolean add( int pos, E o)
Iterator<E> iterator( )
```


Just an Illusion?

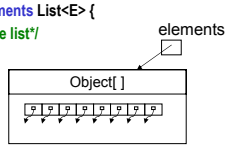
- Key concept: *external view* (the **abstraction** visible to clients) vs. *internal view* (the **implementation**)
- SimpleArrayList may present an illusion to its clients
  - Appears to be a simple, unbounded list of elements
  - Actually may be a complicated internal structure
- The programmer as 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<E> implements List<E> {
    /** variable to hold all elements of the list*/
    private E[ ] elements;
    ...
}
```



- Issues:
  - How big to make the array?
  - 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<E> implements List<E> {
    // instance variables
    private E[ ] 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 DEFAULT_CAPACITY = 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 = (E[]) new Object[capacity]; // new E[capacity] doesn't work!
    this.numElems = 0;
}

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

- 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:

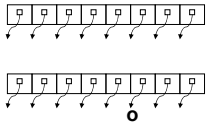
```
/** Return whether the list is empty (has no elements) */
public boolean isEmpty( ) {
    return this.size( ) == 0;  //OR return this.numElems == 0;
}
```

  - 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 true if the object was added successfully.
     This implementation always returns true. */
public boolean add(E 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(E 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; // triggers a garbage collection if it is the only
                               // reference
   }
   // DON'T DO:  for (Object o : elements) { o = null; }   WHY?
   this.numElems = 0;
}
```


Method *get*

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

- Question: is a "throws" clause required?
- Exercise: write out the preconditions more fully
- Exercise: specify and implement the *set* method
- Exercise: rewrite the above with an assert statement

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++) {
      E 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?

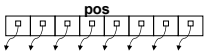
Method *contains*

```
/** 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, implementation-dependent version is possible
- Exercise: define "this list contains object o" more rigorously

remove(pos): Specification

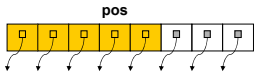
```
/** Remove the object at position pos from this list.  Return the removed
element.
    0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public E remove( int pos) {
...
    return removedElem;
}
```



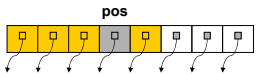
- Postconditions: quite a bit more complicated this time...
  - Try writing them out!
- Key observation for implementation:
  - we need to compact the array after removing something in the middle; slide all later elements left one position

Array Before and After *remove*

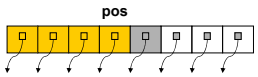
- Before



- After – Wrong!



- After – Right!



remove(pos): Code

```
/** Remove the object at position pos from this list.  Return the removed element.
    0 <= pos < size( ), or IndexOutOfBoundsException is thrown */
public E remove( int pos) {
    if (pos < 0 || pos >= this.numElems) {
      throw new IndexOutOfBoundsException( );
    }
    E 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.elements[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;
    }
}
```

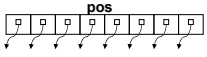
- Pre- and postconditions are not quite the same as remove(pos)

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, E 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, E 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

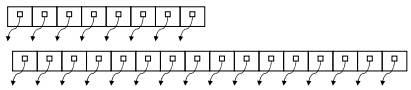
- Our original version of add checked for the case when adding an object to a list with no spare capacity
  - But did not handle it gracefully: threw an exception
- Better handling: "grow" the array
- Problem: Java arrays are fixed size – can't grow or shrink
- Solution: Make a new array of needed size
- 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( E 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;
            E[] newElements = (E[]) 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 (there is an if statement).
- Pre- and Post- conditions?
- Check the method System.arraycopy

Method *iterator*

- Collection interface specifies a method *iterator( )* that returns a suitable Iterator for objects of that class
  - Key Iterator methods: boolean hasNext( ), E 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<E> iterator( ) {
    return new SimpleListIterator(this);
}
```


Class SimpleListIterator (1)

```
/** Iterator helper class for lists */
class SimpleListIterator<E> implements Iterator<E> {
    // instance variables
    private List<E> 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<E> 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 E next( ) {
    if ( ! hasNext( ) ) {
      throw new NoSuchElementException( );
    }
    E 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

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….