Bags, stacks and queues

Simple growable data structures

- Given an infinitely growable collection of things, what are the bare minimum operations you will need to make it useful?
  - *void add(Thing thing)*
  - *Thing remove() throws Exception*
  - *Iterator<Thing> iterator()*
  - *boolean isEmpty()* // required to avoid throwing exception when calling remove().

Simple growable data structures

- But notice that there's one big feature missing:
  - Access by index (or matching value);
- And one other significant missing feature:
  - Navigation

Invariants?

- Elements have no order within the structure?
  - Bag.
- Elements are in order (or reverse order) of addition?
  - Queue;
  - Stack.

Bag: API

Note the use of a generic type for the items

```java
public interface Bag<Item> extends Iterable<Item> {
    /**
     * Update this Bag by adding item.
     * No guarantee is made regarding the ordering of Items in the iterator
     * @param item the item to add
     */
    void add(Item item);
    /**
     * @return true if this bag is empty
     */
    boolean isEmpty();
    /**
     * @return the number of elements in this bag (not the capacity which is an
implementation-dependent feature)
     */
    int size();
}
```

Note the API is an interface which extends another

Note the javadoc essentially documents the API

Is there anything missing?

Example of usage of iterator:

```java
for (Integer t : bag)
StdOut.println(t);
```

Stack: API

```
public interface Stack<Item> {

    /**
     * Update this Stack by adding an item on the top.
     * @param item the item to add
     */
    void push(Item item);
    /**
     * Update this Stack by taking the top item of this Stack.
     * @return the item.
    * @throws Exception
     */
    Item pop() throws Exception;
    /**
     * Take the peek at the item on top of this Stack.
     * @return the item (return null if there is no such item).
     */
    Item peek();
    /**
     * @return true if this stack is empty
     */
    boolean isEmpty();
}
```

Stack does not implement *Iterable* although later we may change this.

We allow this method in order to avoid exception when popping an empty Stack

Queue: API

```java
public interface Queue<Item> {

    /**
     * Update this Queue by adding an item on the "newest" end.
     * @param item the item to add
     */
    void enqueue(Item item);

    /**
     * Update this Queue by taking the oldest item off the queue.
     * @return the item or null if there is no such item.
     */
    Item dequeue();

    /**
     * @return true if this stack is empty
     */
    boolean isEmpty();
}
```

Queue does not implement ***Iterable*** either—although it could.

We don't need to throw an exception on ***dequeue*** when the queue is empty.

Notice any differences…

- …from the book?
  - This is the tricky part of designing an API: there are frequently different opinions. My rules:
    1. do not add any signatures that are not absolutely essential;
    2. split mutating and non-mutating methods into separate interfaces;
    3. separate different concerns.
  - Also, notice that I used interfaces, not classes. Unfortunately, the Java designers started out with a lot of concepts which they implemented as classes (or abstract class) which should have been interfaces (IMO, of course).

How are we going to implement these?

- We may be able to use other data structures:
    - For example, we can probably use:
        - A list for a bag or a stack?
        - A doubly-linked list for a queue?

Bag: Implementation

```
import java.util.Arrays;
import java.util.Iterator;
public class Bag_Array<Item> implements Bag<Item> {
    public Bag_Array() {
        grow((Item[])new Object[0], 32);
    }
    public void add(Item item) {
        if (full())
            grow(items,2 * capacity());
        items[count++] = item;
    }
    public boolean isEmpty() {
        return count==0;
    }
    public int size() {
        return count;
    }
    public Iterator<Item> iterator()  {
        return Arrays.asList(Arrays.copyOf(items,count)).iterator();
    }
    private void grow(Item[] source, int size) {
        items = growFrom(source, size);
    }
    private int capacity() {
        return items.length; // items should always be non-null when this method is called
    }
    private boolean full() {
        return size()==capacity();
    }
    private static <T> T[] growFrom(T[] from, int size) {
        T[] result = (T[])new Object[size];
        System.arraycopy(from, 0, result, 0, from.length);
        return result;
    }
    private Item[] items = null;
    private int count = 0;
}
```

Note the name: concrete classes should have a name that describes how they implemented the interface.

Here we implement the signatures defined by *Bag* and *Iterator*

Note that Java does not provide an iterator for an array :(

Generally, we should put the private stuff at the end of the class.

Bag: Testing

```java
import org.junit.Test;

import static org.junit.Assert.*;

public class BagTest {
    /**
     * Test method for Bag
     */
    @Test
    public void testBag() {
        Bag<Integer> bag = new Bag_Array<>();
        assertTrue(bag.size()==0);
        assertTrue(bag.isEmpty());
        assertFalse((bag.iterator()).hasNext());
        bag.add(1);
        assertTrue(bag.size()==1);
        assertFalse(bag.isEmpty());
        assertTrue(( bag.iterator()).hasNext());
        assertEquals(new Integer(1), bag.iterator().next());
    }
}
```

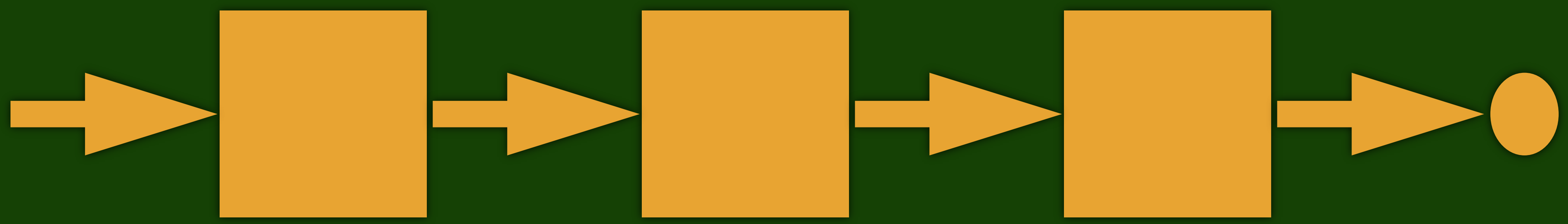
Comparison of storage methods

Technique	Access	Add to Head	Add to Tail	Copy
Array	O(1)	O(1)*	O(1)*	O(N)
Linked List	O(N)†	O(1)	O(N)	O(1) or O(N) if mutable
Doubly-linked List	O(N)†	O(1)	O(1)	O(1) or O(N) if mutable

* Except when full: in which case, a copy is required;

To be precise, average number of accesses is (N+1)/2

Linked Lists



- Each element has two fields:
  - The value of this element;
  - A pointer/reference to the next element (which may be null).
- Addition/removal of an element:
  - at the head is $O(1)$, i.e. constant;
  - at the tail is $O(N)$, i.e. it varies according to the current length N

Stack using LinkedList

- A linked list is perfectly suited to a Stack, because all addition/removal operations (push, pop) happen at the head.
- You can also implement a Stack with an array.

LinkedList: Implementation

```
public class LinkedList<Item> {

    public void add(Item item) {
        Element tail = head;
        head = new Element(item, tail);
    }

     public Item remove() throws BQSException {
        if (head == null) throw new BQSException("collection is empty");
        Item result = head.item;
        head = head.next;
        return result;
    }

    public Item getHead() {
        return isEmpty() ? null : head.item ;
    }

    public boolean isEmpty() {
        return head==null;
    }

    private class Element {
        Element(Item x, Element n) {
            item = x;
            next = n;
        }
        final Item item;
        final Element next;
    }

    private Element head = null;
}
```

For this presentation, at least, we don't create an interface out of this. But in our repo it is an interface.

We've chosen to return ***null*** rather than throw an ***Exception***

Private inner class ***Element*** is immutable

head is mutable which means ***LinkedList*** is mutable.

Stack: Implementation

```
public class Stack_LinkedList<Item> implements Stack<Item> {
    public Stack_LinkedList() {
        list = new LinkedList<>();
    }
    public void push(Item item) {
        list.add(item);
    }
    public Item pop() throws RuntimeException {
        return list.remove();
    }
    public Item peek() {
        return list.getHead();
    }
    public boolean isEmpty() {
        return list.isEmpty();
    }
    private final LinkedList<Item> list;
}
```

All methods are delegated to appropriate LinkedList method (three name changes)

Note that list is marked final

Dijkstra’s two-stack algorithm

- What’s the value of (1+((2+3)*(4*5)))?
- If we had a stack, we could use so-called Reverse Polish Notation:
  - 1 2 3 + 4 5 * * +
    - 1
    - 1,2
    - 1,2,3
    - 1,5
    - 1,5,4
    - 1,5,4,5
    - 1,5,20
    - 1,100
    - 101

Dijkstra’s two-stack algorithm

- See repository: DijkstraTwoStack.java

LinkedLists and Queues

- A linked list is not perfectly suited to a Queue.
- Why not?

Doubly Linked Lists

- Each element has three fields:
  - The value of this element;
  - A pointer/reference to the next element (which may be null).
  - A pointer/reference to the previous element (which may be null).
- Addition/removal of an element:
  - at the head is O(1), i.e. constant;
  - at the tail is O(1), i.e. constant;

Queue with Elements

- Actually, there’s a simpler way to implement a (standard) queue — which only ever enqueues or dequeues a single value at a time:
  - Use Elements (in similar way to *LinkedList*)

Queue: Implementation

```java
public class Queue_Elements<Item> implements Queue<Item> {
    /**
     * Construct a new (empty) queue.
     */
    public Queue_Elements() {
        oldest = null;
        newest = null;
    }
    /**
     * Enqueue the given item into the linked list referenced by oldest
     * @param item the item to add
     */
    public void enqueue( Item item) {
        Element<Item> element = new Element<>(item);
        Element<Item> secondNewest = newest;
        if (isEmpty()) oldest = element;
        else {
            assert secondNewest != null; // Redundant Check
            secondNewest.next = element;
        }
        this.newest = element;
    }
   /**
   * Dequeue an element from the oldest list and return the item.
   * @return the value of the oldest element.
   */
   public Item dequeue() {
        if (isEmpty()) return null;
        else {
            assert oldest != null; // Redundant assertion
             Item result = oldest.item;
            oldest = oldest.next;
            if (isEmpty()) newest = null;
            return result;
        }
    }
    public boolean isEmpty() {
        return oldest == null;
    }
    // This Element essentially begins a LinkedList of Elements which correspond
    // to the elements that can be taken from the queue (head points to the oldest element).
    // However, it is built in manner that requires a pointer to the newest element.
    private Element<Item> oldest;
    // This element always points to the newest (tail-most) element in the LinkedList referenced by oldest.
    private Element<Item> newest;
    private class Element {
        // same as for LinkedList (except that next must be mutable)
   }
}
```

Element constructor with single parameter makes ***next*** pointer null.

We are primarily concerned with ***newest***, but must take care of ***oldest*** when list is empty

oldest always changes but newest only when empty.

oldest essentially implements a linked list while ***newest*** points to its last ***Element***