Problem Set 4:

Stacks & Queues

Note: You will be graded in part on your coding style. Your code should be easy to read, well organized, and concise. You should avoid duplicate code.

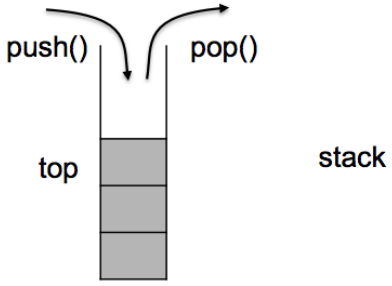
Homework Source: http://www.cs.cmu.edu/~mrmiller/

Background

In this assignment you will be writing one implementation of a stack and two implementations of a queue. Then you will be writing three methods that will use your stack and queue implementations.

Stack

A stack is an abstract data type that allows only a limited number of operations on a collection of data. Elements are stored in order of insertion and the elements are removed in reverse order. Because the last element that is inserted is the first to be removed, it is often referred to as a *Last-in First-out* (LIFO) collection. For this assignment the Java `MyStack` interface specifies the operations that any implementation of a stack must have.

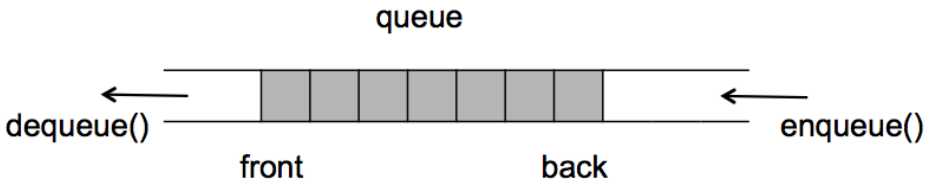


There are several ways that stacks can be implemented. For example, you can use an dynamic array, an ArrayList, a linked list of nodes, or a LinkedList.

For this assignment you will implement a stack using an array.

Queue

A queue is another abstract data type that allows only a limited number of operations on a collection of data. Again, elements are stored in order of insertion. But with queues the elements are removed in the same order. Because the first element that is inserted is the first to be removed, it is often referred to as *First-in First-out* collection. For this assignment the Java`MyQueue` interface specifies the operations that any implementation of a queue must have.



Again, there are several ways that queues can be implemented.

For this assignment you will write two implementations queue, one using an array and other using two stacks.

Assignment

Download hw8.zip. Inside you will find:

- `MyStack` - An interface for the abstract data type stack (given to you).
- `ArrayStack` - A class you will complete that uses an array to implement MyStack.
- `MyQueue` - An interface for the abstract data type queue (given to you).
- `ArrayQueue` - A class you will complete that uses a circular array to implement MyQueue.
- `TwoStackQueue` - A class you will complete that uses two stacks to implement MyQueue.
- `StackQueueSolver` - A class you will complete that solves several problems using stack and/or queues.

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1. **ArrayStack**

   In the `ArrayStack` class, implement the methods of the `MyStack`interface as specified. Be sure to throw exceptions when required. Your stack should be unbounded, like an ArrayList is, where it can grow in size. All the operations must take amortized O(1) time in the worst case.

In addition, implement the `toString` method so that it returns a string in**exactly** the following format (three examples shown with integers):

```
top [ ] bottom       (empty stack) top [ 1 ] bottom
(stack with one element) top [ 5 2 8 ] bottom (stack with 3
elements)
```

Note that the parenthetical remarks are not part of the string returned by toString. Be sure to test your class thoroughly, as you will be using it later in the assignment.

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2. ArrayListQueue

One way we might implement a queue is to use an ArrayList where the back of the queue is at the end of the array and the front of the queue is at the beginning of the array. Although this implementation is clean and simple, it is not efficient.

```
public class ArrayListQueue implements MyQueue {     private
ArrayList queue;     public ArrayListQueue() { queue = new
ArrayList(); }     public E dequeue(){ return queue.remove(0); }
public void enqueue(E element) { queue.add(element); }     public
E peek() { return queue.get(0); } }
```

a) In a comment at the top of your ArrayQueue class, explain why the ArrayListQueue is a poor implementation of Queue in terms of its runtime.

b) Also comment on whether it would be better or the not to make the front of the queue be at the end of the ArrayList and back of the queue be at the front of the ArrayList.

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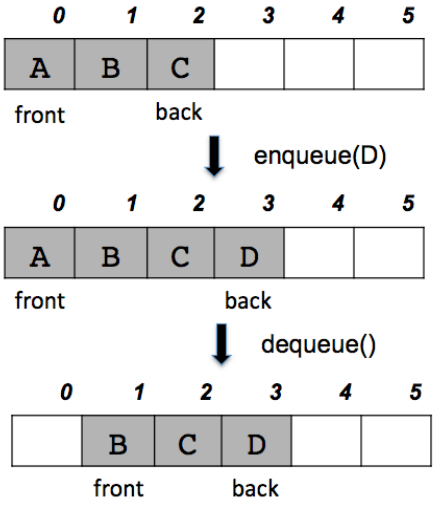
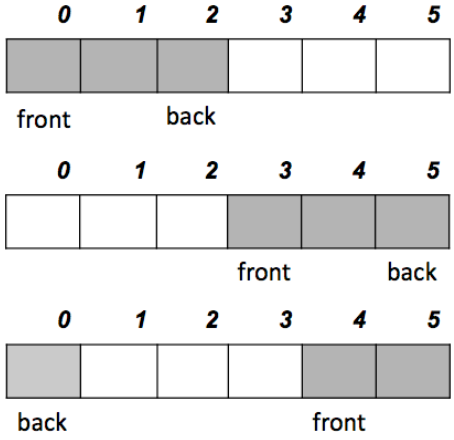
3. ArrayQueue

In order to have an queue implementation using an array that has O(1) amortized runtime for enqueue and O(1) amortized runtime for dequeue, you will not move the elements of the array. You will maintain both the index of the front and the back of the queue. Every time you enqueue an element you increment the back index. Similarly, every time you dequeue an element you increment the front index.



The problem is that, as you enqueue and dequeue elements from the queue, the data in the queue is stored towards the end of the array and space frees up at the beginning of the array. To reuse any unused space at the front of the array, we will consider the array to be a *circular array*. That is, whenever the we reach the end of the array, we "wrap around" to the beginning of the array. At various stages it is possible that elements could be at the front of the array, the middle of the array, the end of the array, or wrapped around the end of the array. (HINT: You may find that the modulus (%) operator is handy for keeping the front and back indices within the index bounds of the array.)



Some configurations of three elements in a queue

Notice that no element in the array moves. Once an element is placed in the array, it stays put and the queue moves forward so that eventually the element is at the front of the queue and is removed with the next dequeue operation.

As with ArrayLists, when the array is full, we can expand the array by copying the queue data to a new longer array. Where should be front of the queue be in the new array?

Although not strictly necessary, it is convenient to have a field that keeps the a count of the number of elements in the queue. (It's also possible to compute the index of the back of the queue from the front index and the number of elements in the queue.)

Implement the methods of the ArrayQueue including the toString method, which should return a string in **exactly** the following format (two examples shown with integers):

```
front: 4 back: 4 front [ 1 ] back      (queue with one
element)
 front: 6 back: 0 front [ 5 2 8 ] back  (queue with 3
elements wrapped)
```

Be sure to test your class thoroughly, as you will be using it later in the assignment.

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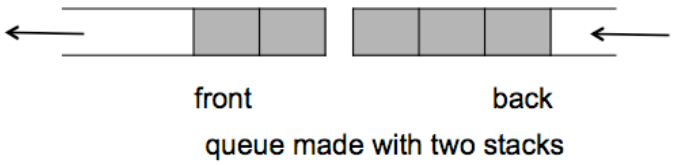
4. TwoStackQueue

A queue can also be implemented using two stacks. One stack is used to enqueue elements, while the other is used to dequeue elements. That is, when an element is added to the queue it is pushed on the `in` stack. When an element is removed from the queue it is popped off the `out`stack. If the `out` stack is empty, the contents of the `in` stack is transfered to the `out` stack.



queue made with two stacks

(Aside: As strange as this implementation may seem, it is a common implementation for purely "functional" programming languages.)

Again, the runtime of the enqueue operation is O(1), as it is simply a push onto the stack. The runtime of the dequeue operation is not so

simple. It is sometimes O(1), as it is a pop operation. Other times it is an O(n) operation, as it has to transfer all the data from the `in` stack to the`out` stack. Dequeue is amortized O(1) time: Each element is pushed on one stack and then transferred to the other stack exactly once.

Implement the methods of the TwoStackQueue. When you implement the toString method, it must format the returned string in the specified format **exactly**. Use a vertical bar to indicate which data is in the `out`stack.

```
front [ 1 | ] back      (queue with one element)
 front [ 5 | 2 8 ] back  (queue with 1 element on the out
stack                          and 2 elements on the in
stack)
```

In addition, the only collection data type you may use is the MyStack collection type, should you require any addition storage. This class fields and additional storage must by of type MyStack, which means you may use only pop, peek, push, and isEmpty. In particular, you may not add extra methods to your ArrayStack class for the convenience of this class.

Be sure to test your class thoroughly.

In the StackQueueSolver class, complete the following methods:

5. At the Ann Oy Bank, a bank teller decides to go to lunch and a line forms with m people. Number the customers 1, 2, ... , m. When the teller returns, the teller tells the person at the head of the line to go to the back of the line, doing this n times. Then the teller serves the person at the head of the line. The teller repeats this process until the line is empty (assuming no one else enters the bank). Write a method `lastCustomer`that has two parameters that specify the number of customers initially in line (m) and the number of customers sent to the back of the line each time (n). The method should return the number of the customer that is served LAST. You may assume that $m > 0$ and $1 \leq n \leq m$. Use a queue to compute your solution.

   In a comment above the method write the worst-case runtime (in Big-O) of your method.

6. Write a method `areEqual` that returns true if the two stacks specified in the parameters have the same elements in the same order, and false otherwise. Two elements are the same if they refer to the same object. The method may remove elements from the stacks, but it must return the elements to the stacks in the same order to restore the stacks to their original state. The only additional data structure that it can use as auxiliary storage is a single stack (i.e., no arrays, no ArrayLists, no linked lists no queues, no strings...). The method may also use O(1) additional space.

   In a comment above the method, write the worst-case runtime (in Big-O) of your method when the two stacks have n elements.

7. Write a method `duplicateStack` that returns a new stack containing the same elements and in the same order as the stack specified in the parameter. The method should create a new stack and fill it with the same data elements as the given stack. (You do not need to duplicate the contents of the elements.) Before the method finishes, it must restore the contents of the original stack to its original state (same contents in the same order). Besides the new stack that the method returns, the only additional data structure that it can use is a single queue. The method may also use O(1) additional space.

   In a comment above the method write the worst-case runtime (in Big-O) of your method when the specified stack has n elements