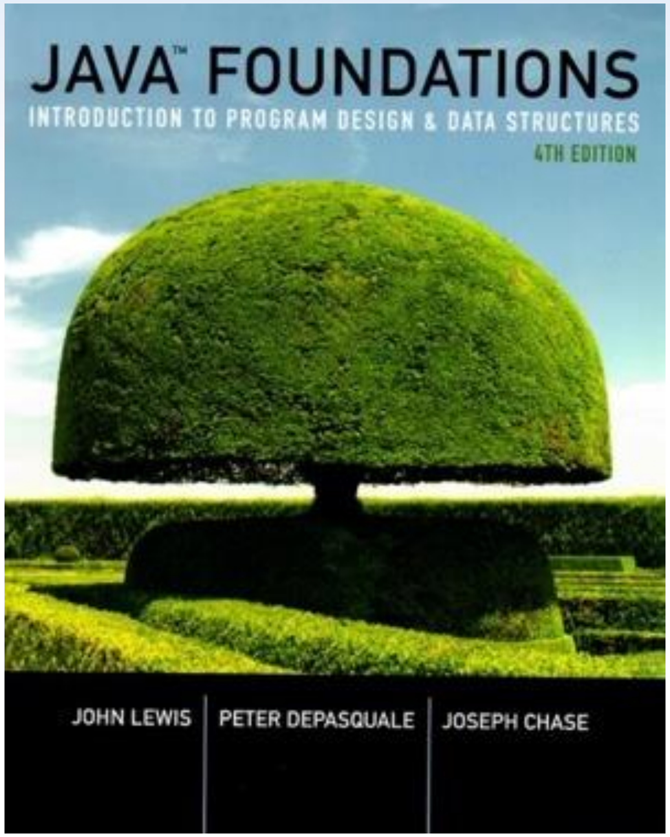


Chapter 14

Queues

Chapter Scope

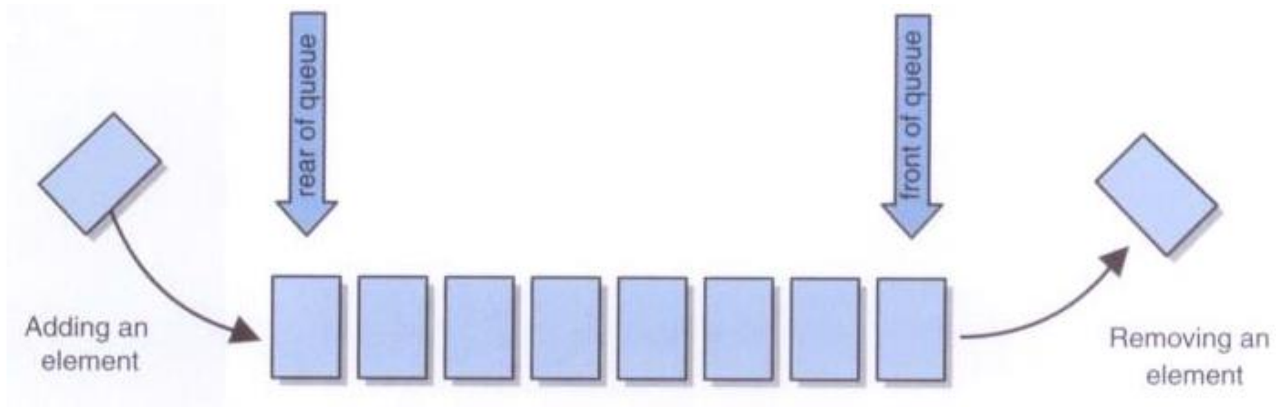
- Queue processing
- Using queues to solve problems
- Various queue implementations
- Comparing queue implementations

Queues

- A *queue* is a collection whose elements are added on one end and removed from the other
- Therefore a queue is managed in a *FIFO* fashion: first in, first out
- Elements are removed in the same order they arrive
- Any waiting line is a queue:
  - the check out line at a grocery store
  - the cars at a stop light
  - an assembly line

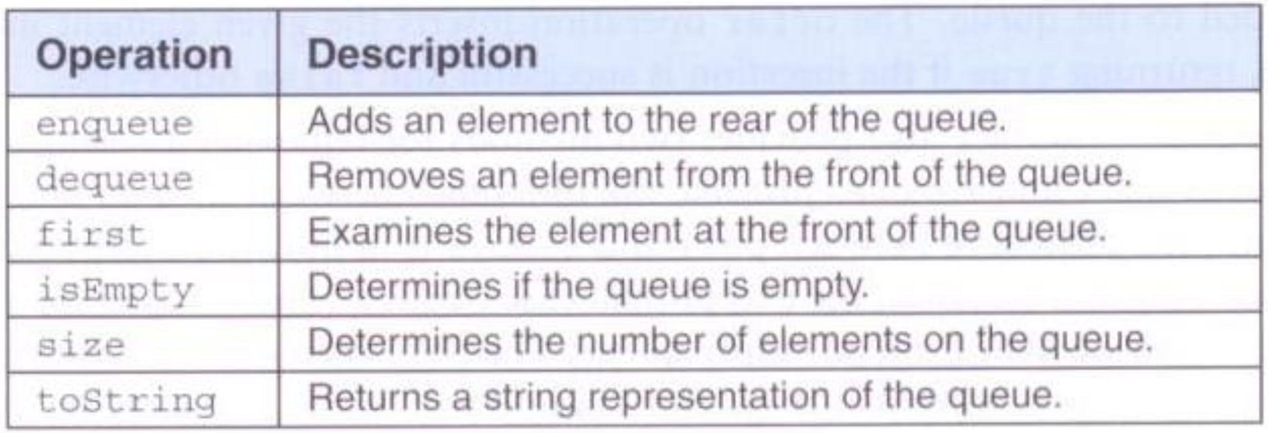
Queues

- A queue, conceptually:



Queues

- Standard queue operations:



Operation	Description
`enqueue`	Adds an element to the rear of the queue.
`dequeue`	Removes an element from the front of the queue.
`first`	Examines the element at the front of the queue.
`isEmpty`	Determines if the queue is empty.
`size`	Determines the number of elements on the queue.
`toString`	Returns a string representation of the queue.

Queues in the Java API

- The Java Collections API is not consistent about its implementation of collections
- For queues, the API provides a `Queue` interface, then various classes such as `LinkedList` implement the interface
- Furthermore, the `Queue` interface defines two versions of the methods that add and remove elements from the queue
- The difference in the two versions is how exceptional situations are handled

Queues in the Java API

- The `add` method throws an exception if the element cannot be added, and the `offer` method returns a boolean indicating success or failure
- When the queue is empty, the `remove` method throws an exception and the `poll` method returns null
- The goal is to give the user the option of handling exceptional cases in whatever way is preferred

Coded Messages

- Let's use a queue to help us encode and decode messages
- A *Ceasar cipher* encodes a message by shifting each letter in a message by a constant amount k
- If k is 5, A becomes F, B becomes G, etc.
- However, this is fairly easy to break
- An improvement can be made by changing how much a letter is shifted depending on where the letter is in the message

Coded Messages

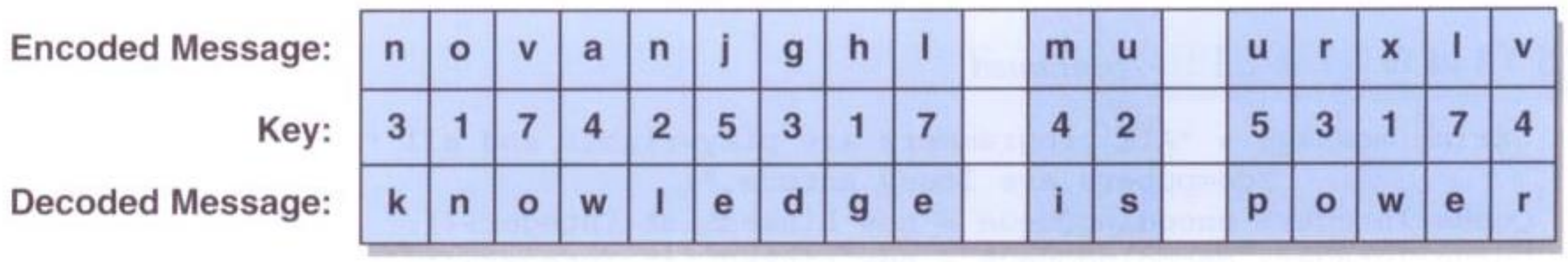
- A *repeating key* is a series of integers that determine how much each character is shifted
- For example, consider the repeating key

3 1 7 4 2 5

- The first character in the message is shifted 3, the next 1, the next 7, and so on
- When the key is exhausted, we just start over at the beginning of the key

Coded Messages

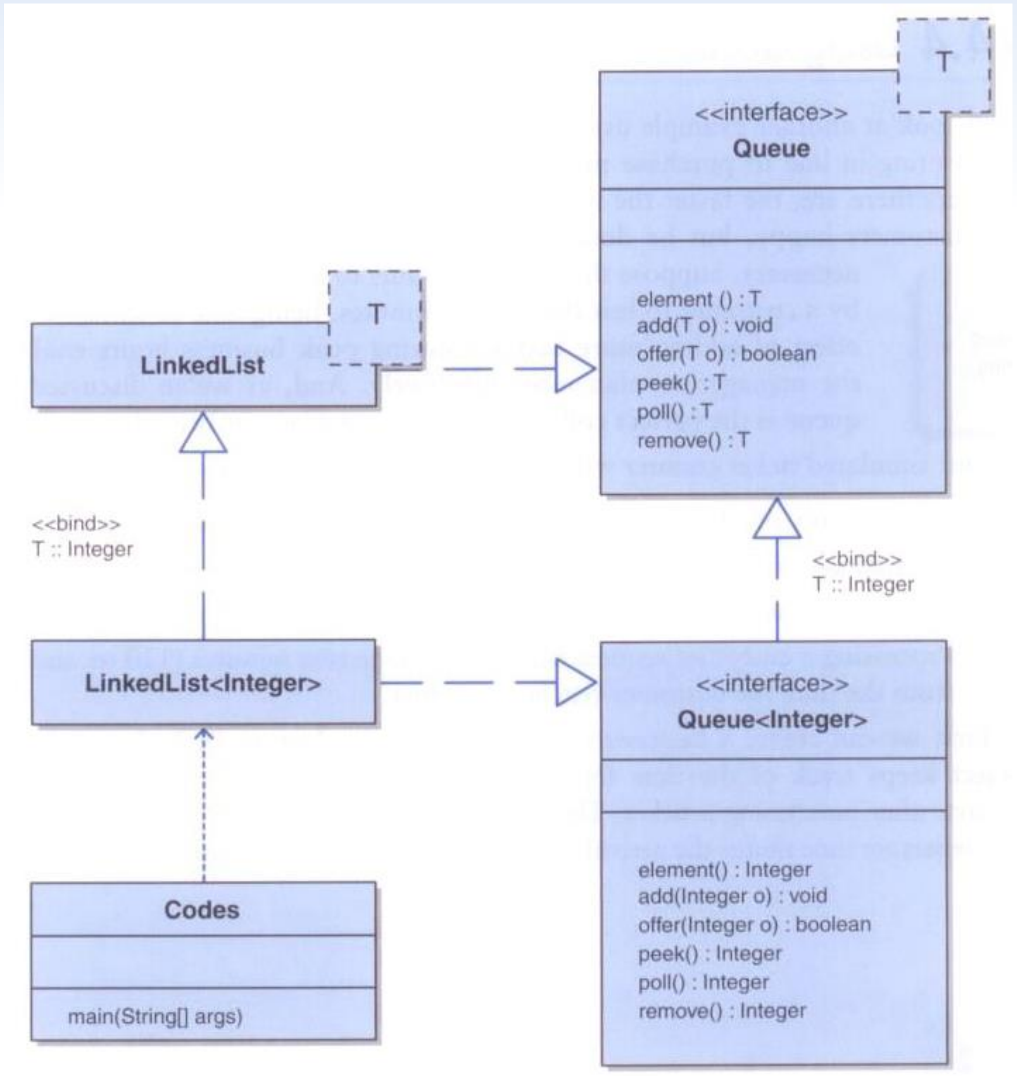
- Decoding a message using a repeating key:



Encoded Message:	n	o	v	a	n	j	g	h	l		m	u		u	r	x	l	v
Key:	3	1	7	4	2	5	3	1	7		4	2		5	3	1	7	4
Decoded Message:	k	n	o	w	l	e	d	g	e		i	s		p	o	w	e	r

```java
/**
 * Codes demonstrates the use of queues to encrypt and decrypt messages.
 *
 * @author Java Foundations
 * @version 4.0
 */
public class Codes
{
    /**
     * Encode and decode a message using a key of values stored in
     * a queue.
     */
    public static void main(String[] args)
    {
        int[] key = {5, 12, -3, 8, -9, 4, 10};
        Integer keyValue;
        String encoded = "", decoded = "";
        String message = "All programmers are playwrights and all " +
                         "computers are lousy actors.";
        Queue<Integer> encodingQueue = new LinkedList<Integer>();
        Queue<Integer> decodingQueue = new LinkedList<Integer>();

        // load key queues
        for (int scan = 0; scan < key.length; scan++)
        {
            encodingQueue.add(key[scan]);
            decodingQueue.add(key[scan]);
        }
        // encode message
        for (int scan = 0; scan < message.length(); scan++)
        {
            keyValue = encodingQueue.remove();
            encoded += (char) (message.charAt(scan) + keyValue);
            encodingQueue.add(keyValue);
        }

        System.out.println ("Encoded Message:\n" + encoded + "\n");

        // decode message
        for (int scan = 0; scan < encoded.length(); scan++)
        {
            keyValue = decodingQueue.remove();
            decoded += (char) (encoded.charAt(scan) - keyValue);
            decodingQueue.add(keyValue);
        }

        System.out.println ("Decoded Message:\n" + decoded);
    }
}
```

Coded Messages



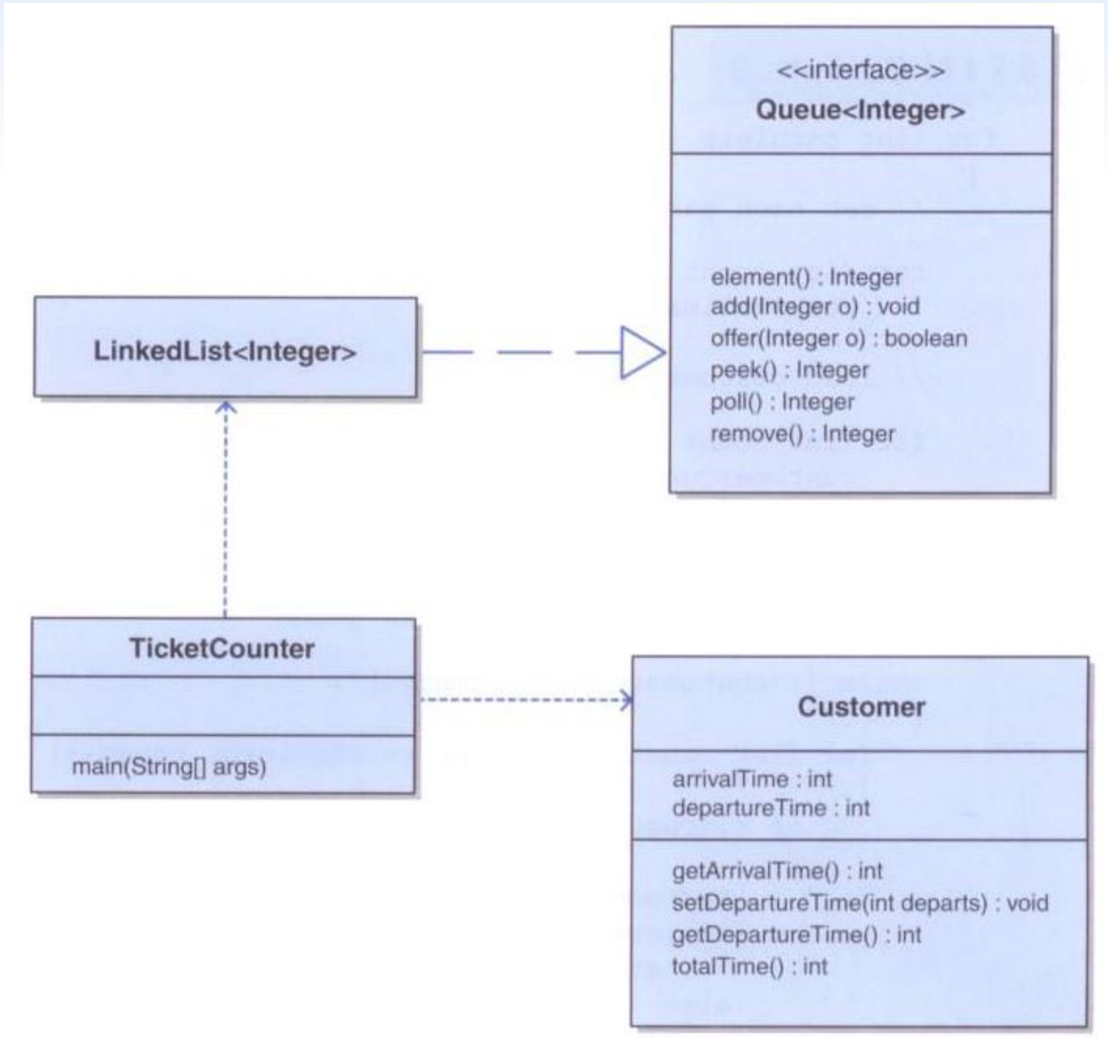
Ticket Counter Simulation

- Now let's use a queue to simulate the waiting line at a movie theatre
- The goal is to determine how many cashiers are needed to keep the wait time below 7 minutes
- We'll assume:
  - customers arrive on average every 15 seconds
  - processing a request takes two minutes once a customer reaches a cashier

```java
/**
 * Customer represents a waiting customer.
 *
 * @author Java Foundations
 * @version 4.0
 */
public class Customer
{
    private int arrivalTime, departureTime;

    /**
     * Creates a new customer with the specified arrival time.
     * @param arrives the arrival time
     */
    public Customer(int arrives)
    {
        arrivalTime = arrives;
        departureTime = 0;
    }

    /**
     * Returns the arrival time of this customer.
     * @return the arrival time
     */
    public int getArrivalTime()
    {
        return arrivalTime;
    }
    /**
     * Sets the departure time for this customer.
     * @param departs the departure time
     **/
    public void setDepartureTime(int departs)
    {
        departureTime = departs;
    }

    /**
     * Returns the departure time of this customer.
     * @return the departure time
     */
    public int getDepartureTime()
    {
        return departureTime;
    }

    /**
     * Computes and returns the total time spent by this customer.
     * @return the total customer time
     */
    public int totalTime()
    {
        return departureTime - arrivalTime;
    }
}
```

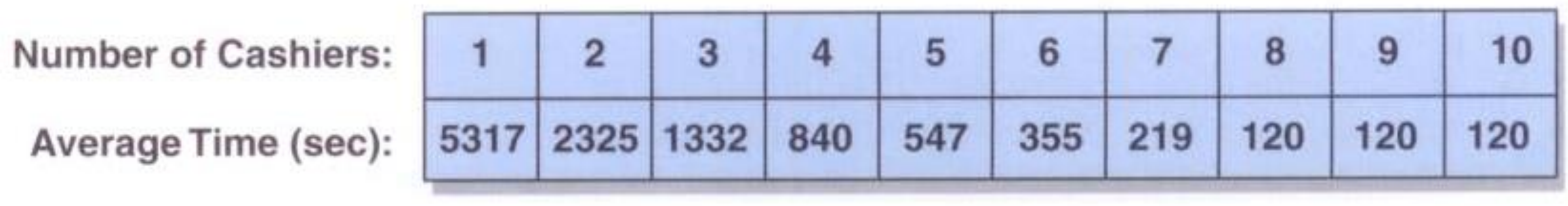
```java
import java.util.*;

/**
 * TicketCounter demonstrates the use of a queue for simulating a line of customers.
 *
 * @author Java Foundations
 * @version 4.0
 */
public class TicketCounter
{
    private final static int PROCESS = 120;
    private final static int MAX_CASHIERS = 10;
    private final static int NUM_CUSTOMERS = 100;

    public static void main(String[] args)
    {
        Customer customer;
        Queue<Customer> customerQueue = new LinkedList<Customer>();
        int[] cashierTime = new int[MAX_CASHIERS];
        int totalTime, averageTime, departs, start;

        // run the simulation for various number of cashiers
        for (int cashiers = 0; cashiers < MAX_CASHIERS; cashiers++)
        {
            // set each cashiers time to zero initially
            for (int count = 0; count < cashiers; count++)
                cashierTime[count] = 0;

            // load customer queue
            for (int count = 1; count <= NUM_CUSTOMERS; count++)
                customerQueue.add(new Customer(count * 15));
            totalTime = 0;

            // process all customers in the queue
            while (!(customerQueue.isEmpty()))
            {
                for (int count = 0; count <= cashiers; count++)
                {
                    if (!(customerQueue.isEmpty()))
                    {
                        customer = customerQueue.remove();
                        if (customer.getArrivalTime() > cashierTime[count])
                                  start = customer.getArrivalTime();
                        else
                            start = cashierTime[count];
                              departs = start + PROCESS;
                            customer.setDepartureTime(departs);
                        cashierTime[count] = departs;
                        totalTime += customer.totalTime();
                    }
                }
            }

            // output results for this simulation
            averageTime = totalTime / NUM_CUSTOMERS;
            System.out.println("Number of cashiers: " + (cashiers + 1));
            System.out.println("Average time: " + averageTime + "\n");
        }
    }
}
```

Ticket Counter Simulation



Ticket Counter Simulation

- The results of the simulation:

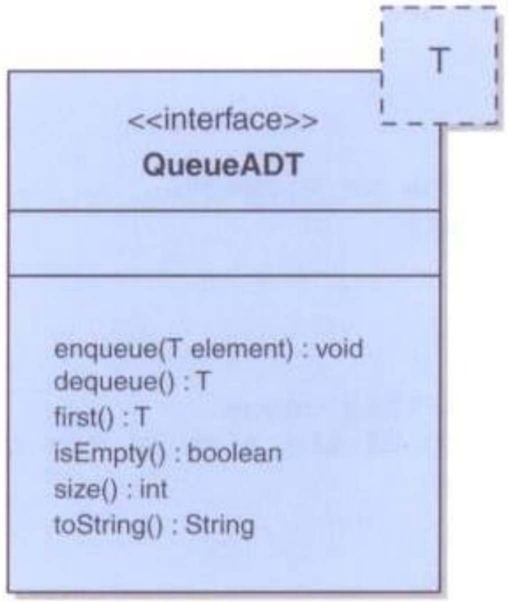


Number of Cashiers:	1	2	3	4	5	6	7	8	9	10
Average Time (sec):	5317	2325	1332	840	547	355	219	120	120	120

- With the goal of an average time of less than seven minutes (420 secs), six cashiers will suffice
- Adding more than eight cashiers will not improve the situation

A Queue ADT

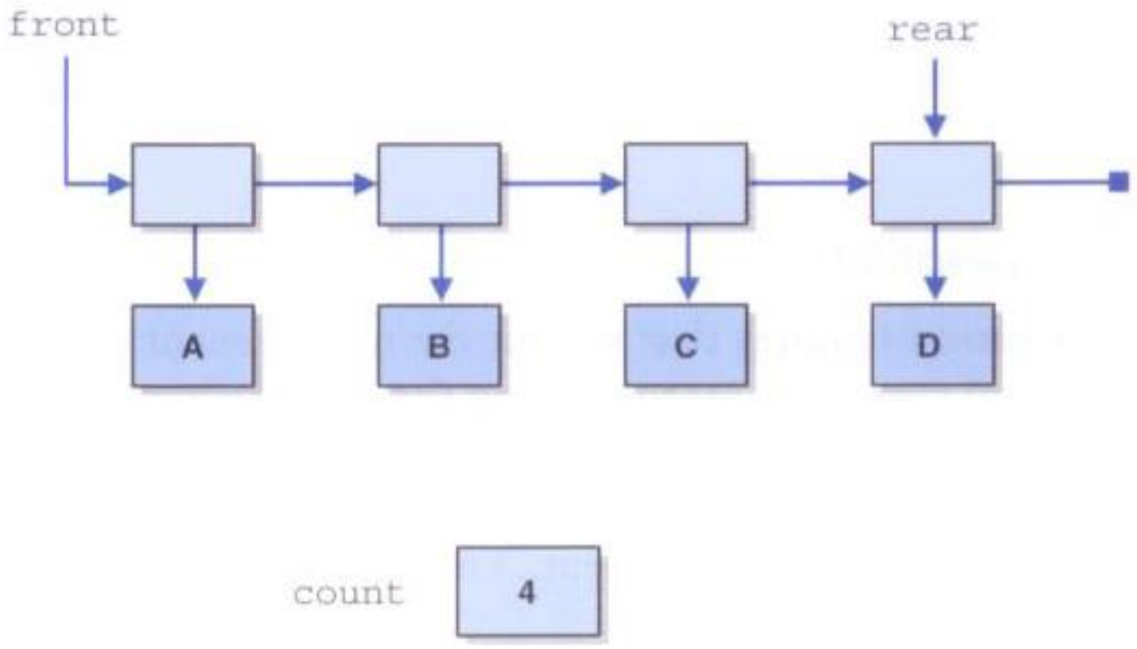
- Defining our own interface for a queue, using only the classic operations:



```java
package jsjf;

/**
 * QueueADT defines the interface to a queue collection.
 *
 * @author Java Foundation
 * @version 4.0
 */
public interface QueueADT<T>
{
    /**
     * Adds one element to the rear of this queue.
     * @param element  the element to be added to the rear of the queue
     */
    public void enqueue(T element);

    /**
     * Removes and returns the element at the front of this queue.
     * @return the element at the front of the queue
     */
    public T dequeue();

    /**
     * Returns without removing the element at the front of this queue.
     * @return the first element in the queue
     */
    public T first();
    /**
     * Returns true if this queue contains no elements.
     * @return true if this queue is empty
     */
    public boolean isEmpty();

    /**
     * Returns the number of elements in this queue.
     * @return the integer representation of the size of the queue
     */
    public int size();

    /**
     * Returns a string representation of this queue.
     * @return the string representation of the queue
     */
    public String toString();
}
```

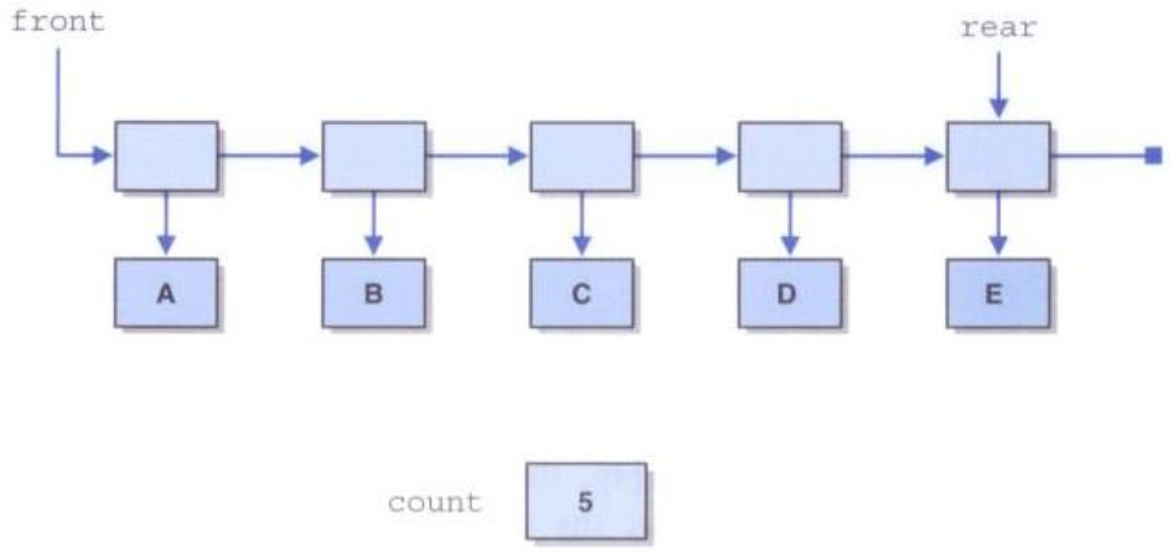
Implementing a Queue with Links

- Since operations work on both ends of the queue, we'll use both front and rear references



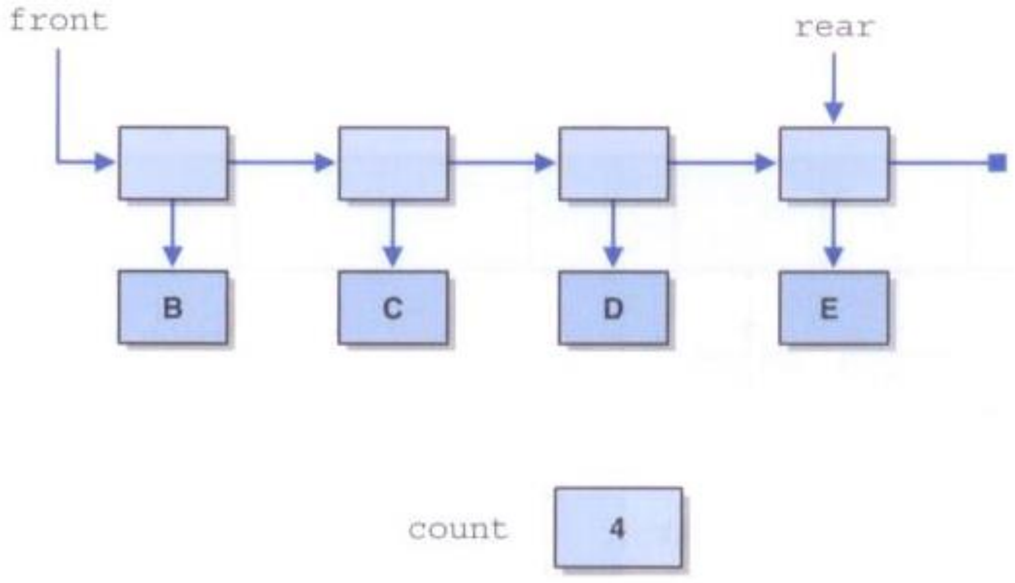
Implementing a Queue with Links

- After adding element E to the rear of the queue:



Implementing a Queue with Links

- After removing an element from the front:



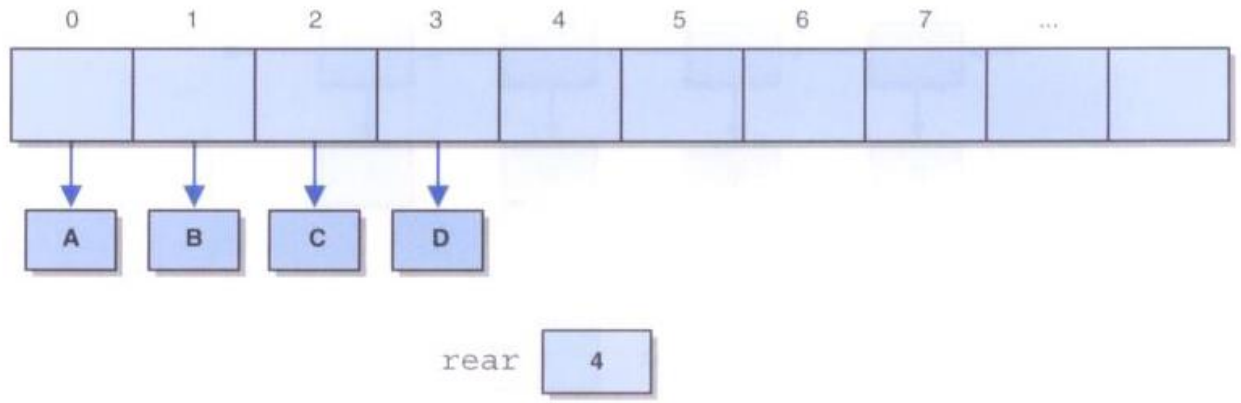
```java
package jsjf;

import jsjf.exceptions.*;

/**
 * LinkedQueue represents a linked implementation of a queue.
 *
 * @author Java Foundations
 * @version 4.0
 */
public class LinkedQueue<T> implements QueueADT<T>
{
    private int count;
    private LinearNode<T> head, tail;

    /**
     * Creates an empty queue.
     */
    public LinkedQueue()
    {
        count = 0;
        head = tail = null;
    }
```

```java
/**
 * Adds the specified element to the tail of this queue.
 * @param element the element to be added to the tail of the queue
 */
public void enqueue(T element)
{
    LinearNode<T> node = new LinearNode<T>(element);

    if (isEmpty())
        head = node;
    else
        tail.setNext(node);

    tail = node;
    count++;
}
```

```
/**
 * Removes the element at the head of this queue and returns a
 * reference to it.
 * @return the element at the head of this queue
 * @throws EmptyCollectionException if the queue is empty
 */
public T dequeue() throws EmptyCollectionException
{
    if (isEmpty())
        throw new EmptyCollectionException("queue");

    T result = head.getElement();
    head = head.getNext();
    count--;

    if (isEmpty())
        tail = null;

    return result;
}
```

Implementing a Queue with an Array

- If we implement a queue as we did a stack, one end would be fixed at index 0:



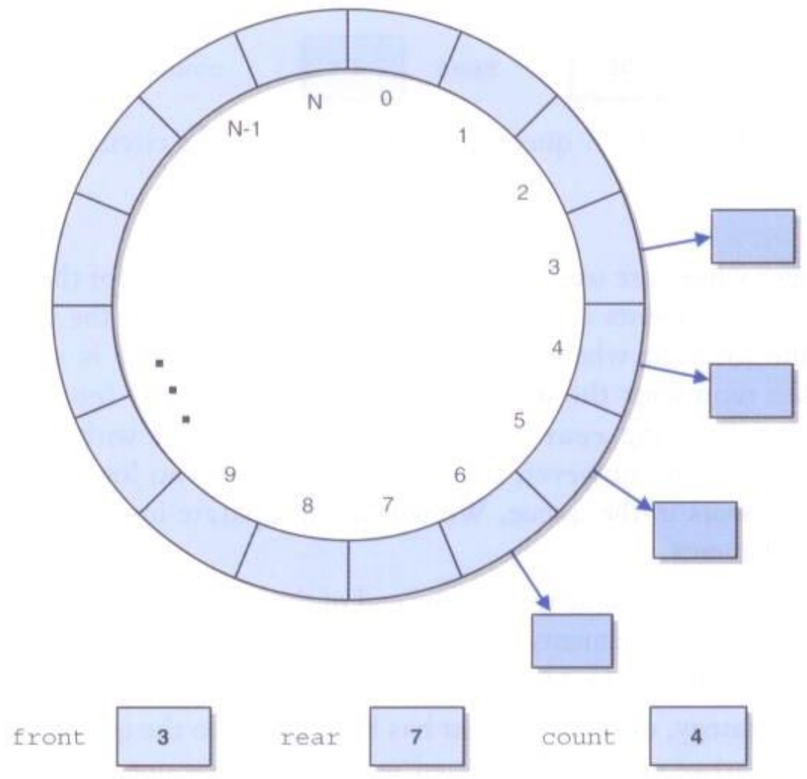
- The problem is that (unlike a stack) a queue operates at both ends
- To be efficient, we must avoid shifting elements

Implementing a Queue with an Array

- A better solution is to treat the array as circular
- A *circular array* is a a regular array that is treated as if it loops back around on itself
- That is, the last index is thought to precede index 0
- We use two integers to keep track of where the front and rear of the queue are at any given time

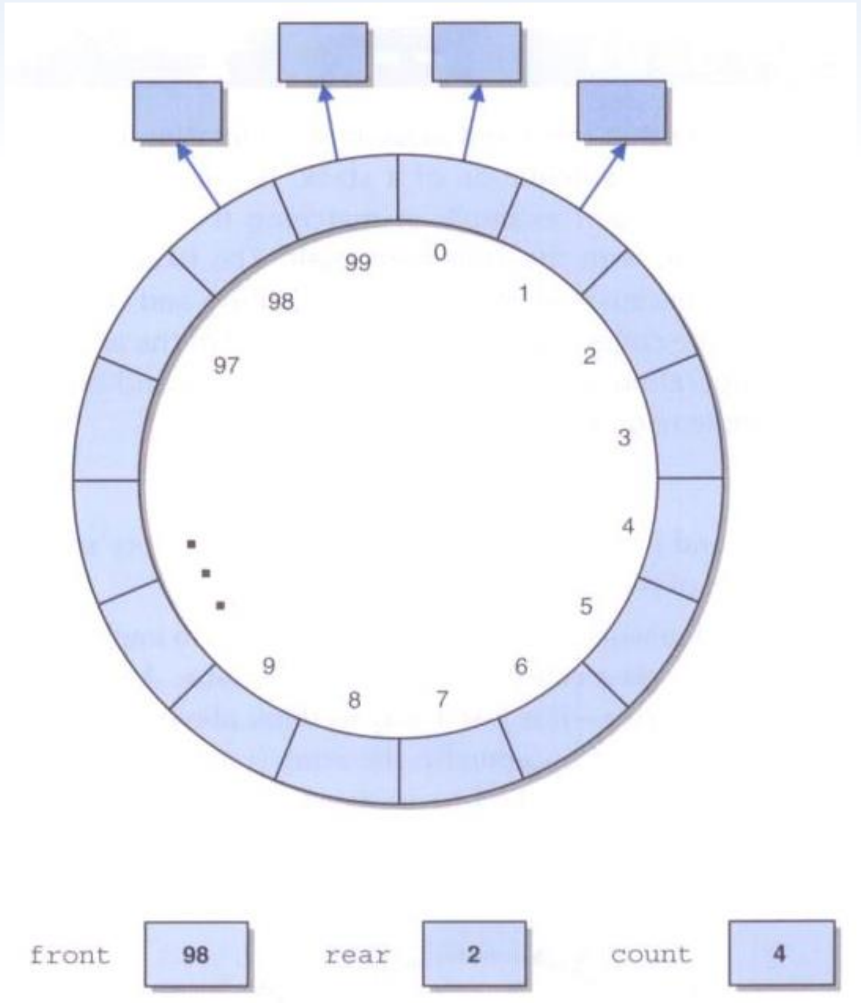
Implementing a Queue with an Array

- A queue implemented using a circular queue:

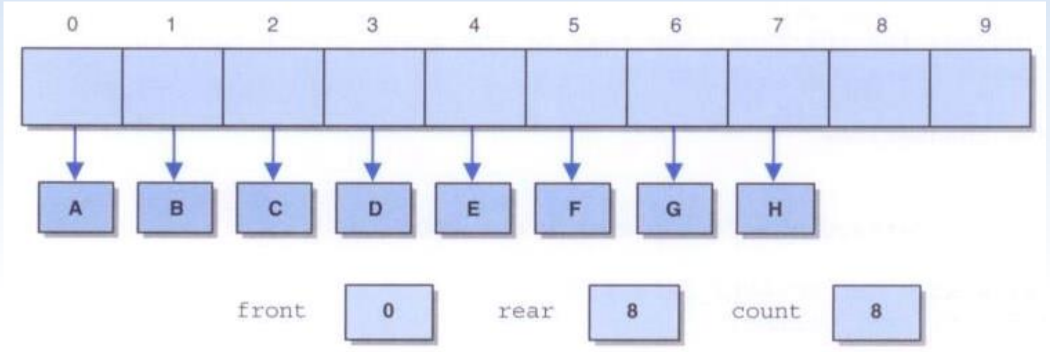


Implementing a Queue with an Array

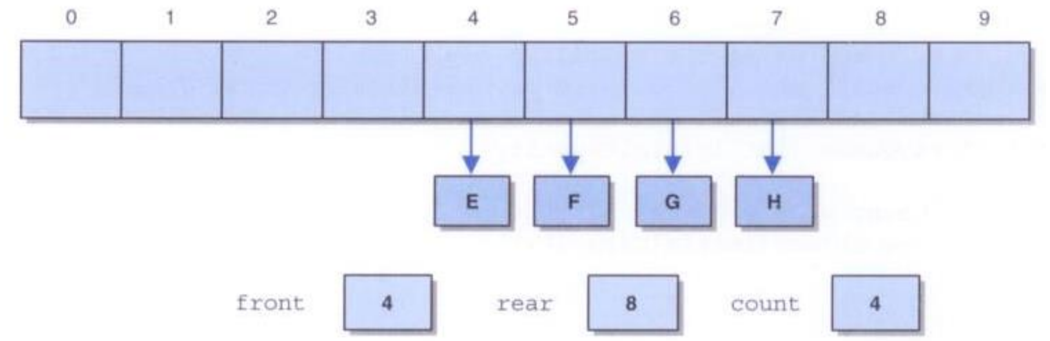
- At some point, the elements of the queue may straddle the end of the array:



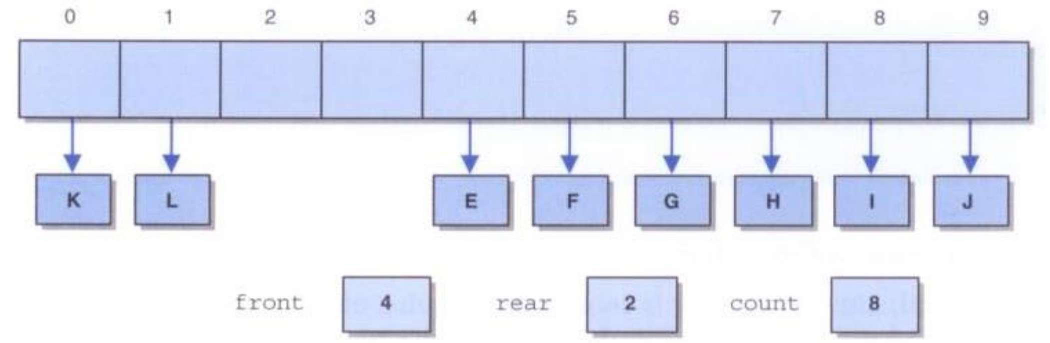
- After A-H have been enqueued:



- After A-D have been dequeueed:

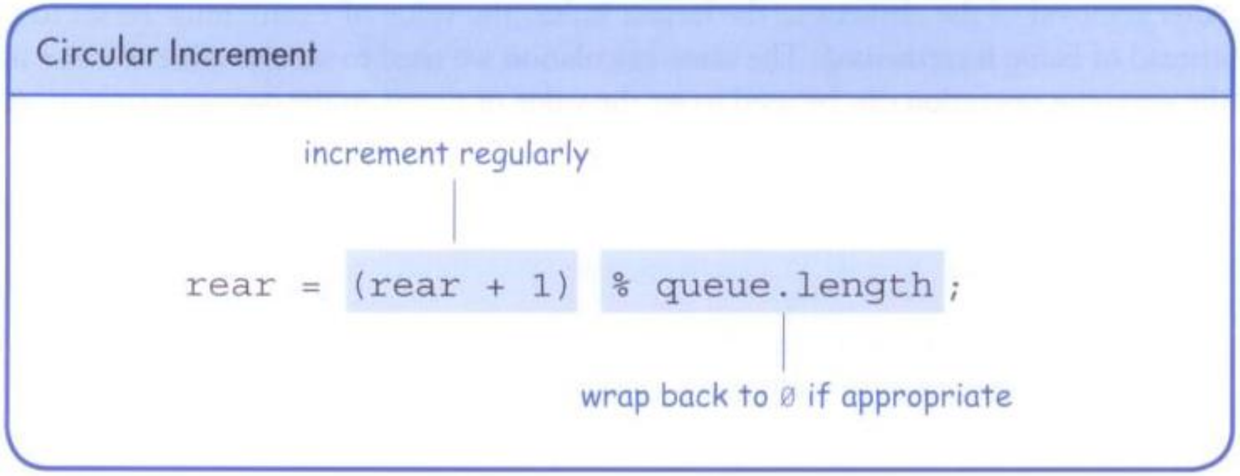


- After I, J, K, and L have been enqueued:



Implementing a Queue with an Array

- Both the `front` and `rear` index values are incremented, wrapping back to 0 when necessary



```
rear = (rear + 1) % queue.length;
```

```java
package jsjf;

import jsjf.exceptions.*;

/**
 * CircularArrayQueue represents an array implementation of a queue in
 * which the indexes for the front and rear of the queue circle back to 0
 * when they reach the end of the array.
 *
 * @author Java Foundations
 * @version 4.0
 */
public class CircularArrayQueue<T> implements QueueADT<T>
{
    private final static int DEFAULT_CAPACITY = 100;
    private int front, rear, count;
    private T[] queue;
```

```java
/**
 * Creates an empty queue using the specified capacity.
 * @param initialCapacity the initial size of the circular array queue
 */
public CircularArrayQueue (int initialCapacity)
{
    front = rear = count = 0;
    queue = (T[]) (new Object[initialCapacity]);
}

/**
 * Creates an empty queue using the default capacity.
 */
public CircularArrayQueue()
{
    this(DEFAULT_CAPACITY);
}
```

```
/**
 * Adds the specified element to the rear of this queue, expanding
 * the capacity of the queue array if necessary.
 * @param element the element to add to the rear of the queue
 */
public void enqueue(T element)
{
    if (size() == queue.length)
        expandCapacity();

    queue[rear] = element;
    rear = (rear+1) % queue.length;

    count++;
}
```

```java
/**
 * Creates a new array to store the contents of this queue with
 * twice the capacity of the old one.
 */
private void expandCapacity()
{
    T[] larger = (T[]) (new Object[queue.length *2]);

    for (int scan = 0; scan < count; scan++)
    {
        larger[scan] = queue[front];
        front = (front + 1) % queue.length;
    }

    front = 0;
    rear = count;
    queue = larger;
}
```

```java
/**
 * Removes the element at the front of this queue and returns a
 * reference to it.
 * @return the element removed from the front of the queue
 * @throws EmptyCollectionException  if the queue is empty
 */
public T dequeue() throws EmptyCollectionException
{
    if (isEmpty())
        throw new EmptyCollectionException("queue");

    T result = queue[front];
    queue[front] = null;
    front = (front+1) % queue.length;

    count--;

    return result;
}
```