Queues
The Queue ADT (§4.3)

- The Queue ADT stores arbitrary objects.
- Insertions and deletions follow the first-in first-out scheme.
- Insertions are at the rear of the queue and removals are at the front of the queue.
- Main queue operations:
  - enqueue(object): inserts an element at the end of the queue.
  - object dequeue(): removes and returns the element at the front of the queue.
- Auxiliary queue operations:
  - object front(): returns the element at the front without removing it.
  - integer size(): returns the number of elements stored.
  - boolean isEmpty(): indicates whether no elements are stored.
- Exceptions:
  - Attempting the execution of dequeue or front on an empty queue throws an EmptyQueueException.
## Queue Example

<table>
<thead>
<tr>
<th>Operation</th>
<th>Output</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>enqueue(5)</td>
<td>–</td>
<td>(5)</td>
</tr>
<tr>
<td>enqueue(3)</td>
<td>–</td>
<td>(5, 3)</td>
</tr>
<tr>
<td>dequeue()</td>
<td>5</td>
<td>(3)</td>
</tr>
<tr>
<td>enqueue(7)</td>
<td>–</td>
<td>(3, 7)</td>
</tr>
<tr>
<td>dequeue()</td>
<td>3</td>
<td>(7)</td>
</tr>
<tr>
<td>front()</td>
<td>7</td>
<td>(7)</td>
</tr>
<tr>
<td>dequeue()</td>
<td>7</td>
<td>()</td>
</tr>
<tr>
<td>dequeue()</td>
<td>“error”</td>
<td>()</td>
</tr>
<tr>
<td>isEmpty()</td>
<td>true</td>
<td>()</td>
</tr>
<tr>
<td>enqueue(9)</td>
<td>–</td>
<td>(9)</td>
</tr>
<tr>
<td>enqueue(7)</td>
<td>–</td>
<td>(9, 7)</td>
</tr>
<tr>
<td>size()</td>
<td>2</td>
<td>(9, 7)</td>
</tr>
<tr>
<td>enqueue(3)</td>
<td>–</td>
<td>(9, 7)</td>
</tr>
<tr>
<td>enqueue(5)</td>
<td>–</td>
<td>(9, 7, 3)</td>
</tr>
<tr>
<td>dequeue()</td>
<td>9</td>
<td>(7, 3, 5)</td>
</tr>
</tbody>
</table>
Applications of Queues

Direct applications
- Waiting lists, bureaucracy
- Access to shared resources (e.g., printer)
- Multiprogramming

Indirect applications
- Auxiliary data structure for algorithms
- Component of other data structures
Array-based Queue

- Use an array of size $N$ in a circular fashion.
- Two variables keep track of the front and rear:
  - $f$: index of the front element
  - $r$: index immediately past the rear element
- Array location $r$ is kept empty.

**normal configuration**

```
Q 0 1 2 f
```

**wrapped-around configuration**

```
Q 0 1 2 r f
```
Queue Operations

We use the modulo operator (remainder of division)

Algorithm `size()`
return \((N - f + r) \mod N\)

Algorithm `isEmpty()`
return \((f = r)\)
Queue Operations (cont.)

- Operation enqueue throws an exception if the array is full.
- This exception is implementation-dependent.

### Algorithm `enqueue(o)`

```plaintext
if size() = N - 1 then
    throw FullQueueException
else
    Q[r] ← o
    r ← (r + 1) mod N
```

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Queues
Queue Operations (cont.)

- Operation dequeue throws an exception if the queue is empty.
- This exception is specified in the queue ADT.

**Algorithm dequeue()**

```plaintext
if isEmpty() then
    throw EmptyQueueException
else
    o ← Q[f]
    f ← (f + 1) mod N
    return o
```

<table>
<thead>
<tr>
<th>Q</th>
<th>0 1 2</th>
<th>f</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>0 1 2</td>
<td>r</td>
<td>f</td>
</tr>
</tbody>
</table>
Queue Interface in Java

- Java interface corresponding to our Queue ADT
- Requires the definition of class EmptyQueueException
- No corresponding built-in Java class

```java
public interface Queue {
    public int size();
    public boolean isEmpty();
    public Object front() throws EmptyQueueException;
    public void enqueue(Object o);
    public Object dequeue() throws EmptyQueueException;
}
```
Application: Round Robin Schedulers

We can implement a round robin scheduler using a queue, $Q$, by repeatedly performing the following steps:

1. $e = Q.dequeue()$
2. Service element $e$
3. $Q.enqueue(e)$