Chapter 8

Queues

The Abstract Data Type Queue

- A queue
  - New items enter at the back, or rear, of the queue
  - Items leave from the front of the queue
  - First-in, first-out (FIFO) property
    - The first item inserted into a queue is the first item to leave

The Abstract Data Type Queue

- ADT queue operations
  - Create an empty queue
  - Determine whether a queue is empty
  - Add a new item to the queue
  - Remove from the queue the item that was added earliest
  - Remove all the items from the queue
  - Retrieve from the queue the item that was added earliest

The Abstract Data Type Queue

- Queues
  - Are appropriate for many real-world situations
    - Example: A line to buy a movie ticket
  - Have applications in computer science
    - Example: A request to print a document
- A simulation
  - Discrete event simulator

The Abstract Data Type Queue

- Pseudocode for the ADT queue operations

```
createQueue()
// Creates an empty queue.

isEmpty()
// Determines whether a queue is empty

enqueue(newItem) throws QueueException
// Adds newItem at the back of a queue. Throws
// QueueException if the operation is not
// successful
```


The Abstract Data Type Queue

- Pseudocode for the ADT queue operations (Cont)

```
dequeue() throws QueueException
// Retrieves and removes the front of a queue.
// Throws QueueException if the operation is
// not successful.

dequeueAll()
// Removes all items from a queue

peek() throws QueueException
// Retrieves the front of a queue. Throws
// QueueException if the retrieval is not
// successful
```

The Abstract Data Type Queue

Operation	Queue after operation
	Front
`queue.createQueue()`	
`queue.enqueue(5)`	5
`queue.enqueue(2)`	5 2
`queue.enqueue(7)`	5 2 7
`queueFront = queue.peek()`	5 2 7 (`queueFront` is 5)
`queueFront = queue.dequeue()`	5 2 7 (`queueFront` is 5)
`queueFront = queue.dequeue()`	2 7 (`queueFront` is 2)

Figure 8-2

Some queue operations

Simple Applications of the ADT Queue: Reading a String of Characters

- A queue can retain characters in the order in which they are typed

```
queue.createQueue()
while (not end of line) {
  Read a new character ch
  queue.enqueue(ch)
}
```

- Once the characters are in a queue, the system can process them as necessary

Recognizing Palindromes

- A palindrome
  - A string of characters that reads the same from left to right as its does from right to left
- To recognize a palindrome, a queue can be used in conjunction with a stack
  - A stack can be used to reverse the order of occurrences
  - A queue can be used to preserve the order of occurrences

Recognizing Palindromes

- A nonrecursive recognition algorithm for palindromes
  - As you traverse the character string from left to right, insert each character into both a queue and a stack
  - Compare the characters at the front of the queue and the top of the stack

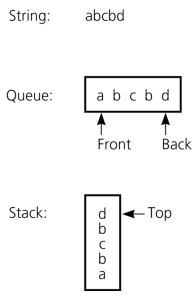

Figure 8-3

The results of inserting a string into both a queue and a stack

Implementations of the ADT Queue

- A queue can have either
  - An array-based implementation
  - A reference-based implementation

A Reference-Based Implementation

- Possible implementations of a queue
  - A linear linked list with two external references
    - A reference to the front
    - A reference to the back

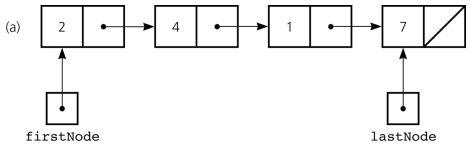

Figure 8-4a

A reference-based implementation of a queue: a) a linear linked list with two external references

A Reference-Based Implementation

- Possible implementations of a queue (Continued)
  - A circular linked list with one external reference
    - A reference to the back

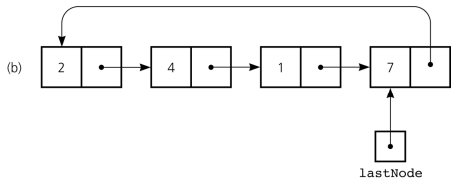

Figure 8-4b
A reference-based implementation of a queue: b) a circular linear linked list with one external reference

A Reference-Based Implementation

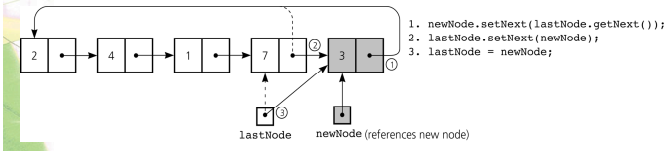

Figure 8-5
Inserting an item into a nonempty queue

A Reference-Based Implementation

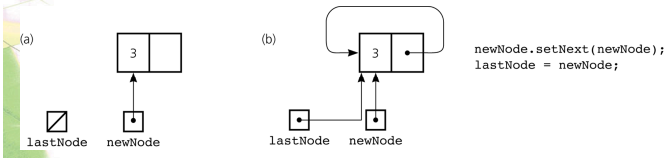

Figure 8-6
Inserting an item into an empty queue: a) before insertion; b) after insertion

A Reference-Based Implementation

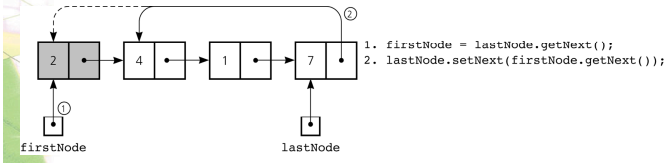

Figure 8-7
Deleting an item from a queue of more than one item

An Array-Based Implementation

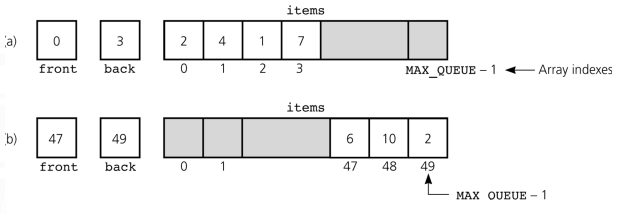

Figure 8-8
a) A naive array-based implementation of a queue; b) rightward drift can cause the queue to appear full

An Array-Based Implementation

- A circular array eliminates the problem of rightward drift

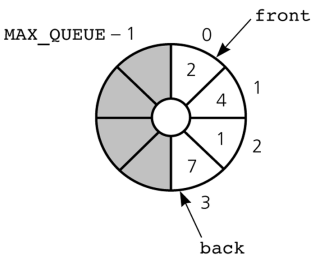

Figure 8-9
A circular implementation of a queue

An Array-Based Implementation

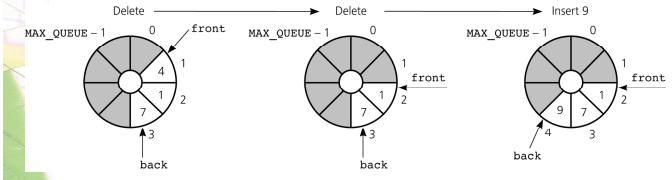

Figure 8-10

The effect of some operations of the queue in Figure 8-8

An Array-Based Implementation

- A problem with the circular array implementation
  - `front` and `back` cannot be used to distinguish between queue-full and queue-empty conditions

An Array-Based Implementation

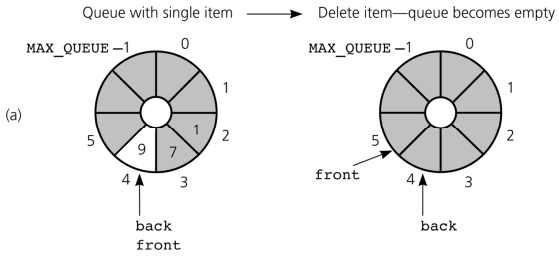

Figure 8-11a

a) ***front*** passes ***back*** when the queue becomes empty

An Array-Based Implementation

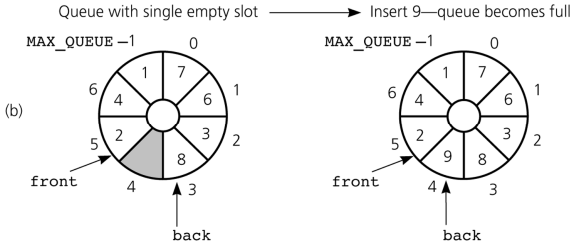

Figure 8-11b

b) ***back*** catches up to ***front*** when the queue becomes full

An Array-Based Implementation

- To detect queue-full and queue-empty conditions
  - Keep a count of the queue items
- To initialize the queue, set
  - `front` to 0
  - `back` to `MAX_QUEUE - 1`
  - `count` to 0

An Array-Based Implementation

- Inserting into a queue

```
back = (back+1) % MAX_QUEUE;
items[back] = newItem;
count++;
```

- Deleting from a queue

```
front = (front+1) % MAX_QUEUE;
count--;
```

An Array-Based Implementation

- Variations of the array-based implementation
  - Use a flag `full` to distinguish between the full and empty conditions
  - Declare `MAX_QUEUE + 1` locations for the array items, but use only `MAX_QUEUE` of them for queue items

An Array-Based Implementation

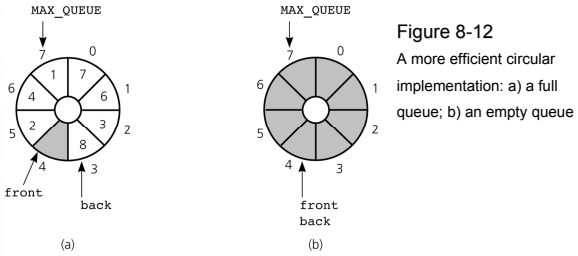

Figure 8-12
A more efficient circular implementation: a) a full queue; b) an empty queue

An Implementation That Uses the ADT List

- If the item in position 1 of a list `list` represents the front of the queue, the following implementations can be used
  - `dequeue()`

```
list.remove(1)
```

  - `peek()`

```
list.get(1)
```


An Implementation That Uses the ADT List

- If the item at the end of the list represents the back of the queue, the following implementations can be used
  - `enqueue(newItem)`

```
list.add(list.size()+1, newItem)
```

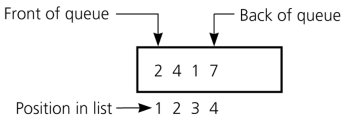

Figure 8-13
An implementation that uses the ADT list

The Java Collections Framework Interface `Queue`

- JCF has a queue interface called **`Queue`**
- Derived from interface **`Collection`**
- Adds methods:
  - `element`: retrieves, but does not remove head
  - `offer`: inserts element into queue
  - `peek`: retrieves, but does not remove head
  - `poll`: retrieves and removes head
  - `remove`: retrieves and removes head

Comparing Implementations

- All of the implementations of the ADT queue mentioned are ultimately either
  - Array based
  - Reference based
- Fixed size versus dynamic size
  - A statically allocated array
    - Prevents the `enqueue` operation from adding an item to the queue if the array is full
  - A resizable array or a reference-based implementation
    - Does not impose this restriction on the `enqueue` operation

Comparing Implementations

- Reference-based implementations
  - A linked list implementation
    - More efficient
  - The ADT list implementation
    - Simpler to write

A Summary of Position-Oriented ADTs

- Position-oriented ADTs
  - List
  - Stack
  - Queue
- Stacks and queues
  - Only the end positions can be accessed
- Lists
  - All positions can be accessed

A Summary of Position-Oriented ADTs

- Stacks and queues are very similar
  - Operations of stacks and queues can be paired off as
    - `createStack` and `createQueue`
    - Stack `isEmpty` and queue `isEmpty`
    - `push` and `enqueue`
    - `pop` and `dequeue`
    - Stack `peek` and queue `peek`

A Summary of Position-Oriented ADTs

- ADT list operations generalize stack and queue operations
  - `length`
  - `add`
  - `remove`
  - `get`

Application: Simulation

- Simulation
  - A technique for modeling the behavior of both natural and human-made systems
  - Goal
    - Generate statistics that summarize the performance of an existing system
    - Predict the performance of a proposed system
  - Example
    - A simulation of the behavior of a bank

Application: Simulation

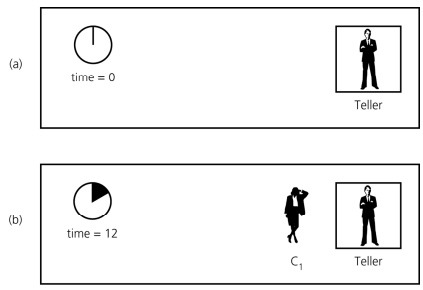

Figure 8-14a and 8-14b

A blank line at at time a) 0; b) 12

Application: Simulation

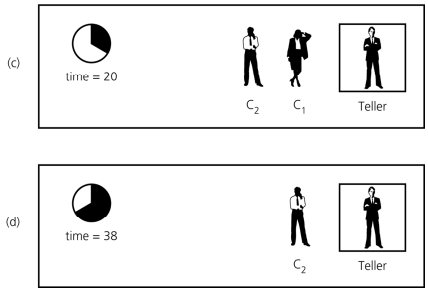

Figure 8-14c and 8-14d

A blank line at at time c) 20; d) 38

Application: Simulation

- An event-driven simulation
  - Simulated time is advanced to the time of the next event
  - Events are generated by a mathematical model that is based on statistics and probability
- A time-driven simulation
  - Simulated time is advanced by a single time unit
  - The time of an event, such as an arrival or departure, is determined randomly and compared with a simulated clock

Application: Simulation

- The bank simulation is concerned with
  - Arrival events
    - Indicate the arrival at the bank of a new customer
    - External events: the input file specifies the times at which the arrival events occur
  - Departure events
    - Indicate the departure from the bank of a customer who has completed a transaction
    - Internal events: the simulation determines the times at which the departure events occur

Application: Simulation

- An event list is needed to implement an event-driven simulation
  - An event list
    - Keeps track of arrival and departure events that will occur but have not occurred yet
    - Contains at most one arrival event and one departure event

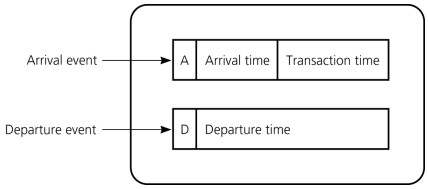

Figure 8-15

A typical instance of the event list

Summary

- The definition of the queue operations gives the ADT queue first-in, first-out (FIFO) behavior
- A reference-based implementation of a queue uses either
  - A circular linked list
  - A linear linked list with a head reference and a tail reference
- An array-based implementation of a queue is prone to rightward drift
  - A circular array eliminates the problem of rightward drift

Summary

- To distinguish between the queue-full and queue-empty conditions in a queue implementation that uses a circular array, you can
  - Count the number of items in the queue
  - Use a `full` flag
  - Leave one array location empty
- Models of real-world systems often use queues
  - The event-driven simulation in this chapter uses a queue to model a line of customers in a bank

Summary

- Simulations
  - Central to a simulation is the notion of simulated time
    - In a time-driven simulation
      - Simulated time is advanced by a single time unit
    - In an event-driven simulation
      - Simulated time is advanced to the time of the next event
  - To implement an event-driven simulation, you maintain an event list that contains events that have not yet occurred