CS 570: Data Structures

Queues

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CHAPTER 4 (PART 2)

Queues

Chapter Objectives

- To learn how to use the methods in the `Queue` interface for insertion (`offer` and `add`), removal (`remove` and `poll`), and for accessing the element at the front (`peek` and `element`)
- To understand how to implement the `Queue` interface using a single-linked list, a circular array, and a double-linked list
- To become familiar with the `Deque` interface and how to use its methods to insert and remove items from either end of a deque

Week 7

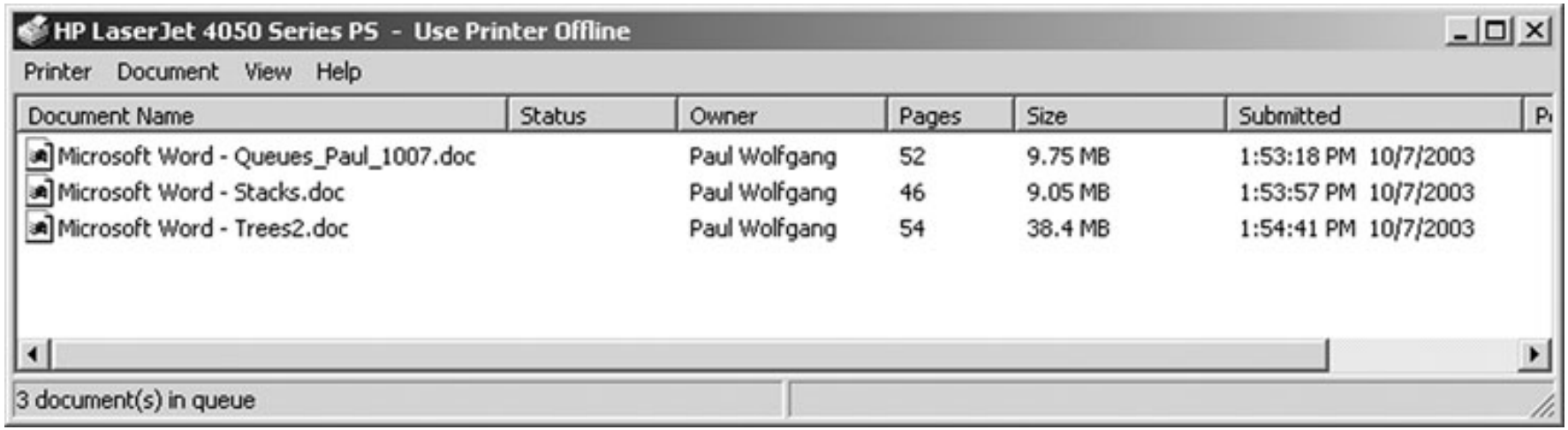
- Reading Assignment: Koffman and Wolfgang, Sections 4.5-4.8

Queue

- The queue, like the stack, is a widely used data structure
- A queue differs from a stack in one important way
  - A stack is LIFO list – *Last-In, First-Out*
  - while a queue is FIFO list, *First-In, First-Out*

Example: Print Queue

- Operating systems use queues to
  - keep track of tasks waiting for a scarce resource
  - ensure that the tasks are carried out in the order they were generated
- Print queue: printing is much slower than the process of selecting pages to print, so a queue is used



Unsuitability of a Print Stack

- Stacks are Last-In, First-Out (LIFO)
- The most recently selected document would be the next to print
- Unless the printer stack is empty, your print job may never be executed if others are issuing print jobs

Specification for a Queue Interface

Method	Behavior
`boolean offer(E item)`	Inserts `item` at the rear of the queue. Returns **`true`** if successful; returns **`false`** if the item could not be inserted.
`E remove()`	Removes the entry at the front of the queue and returns it if the queue is not empty. If the queue is empty, throws a `NoSuchElementException`.
`E poll()`	Removes the entry at the front of the queue and returns it; returns **`null`** if the queue is empty.
`E peek()`	Returns the entry at the front of the queue without removing it; returns **`null`** if the queue is empty.
`E element()`	Returns the entry at the front of the queue without removing it. If the queue is empty, throws a `NoSuchElementException`.

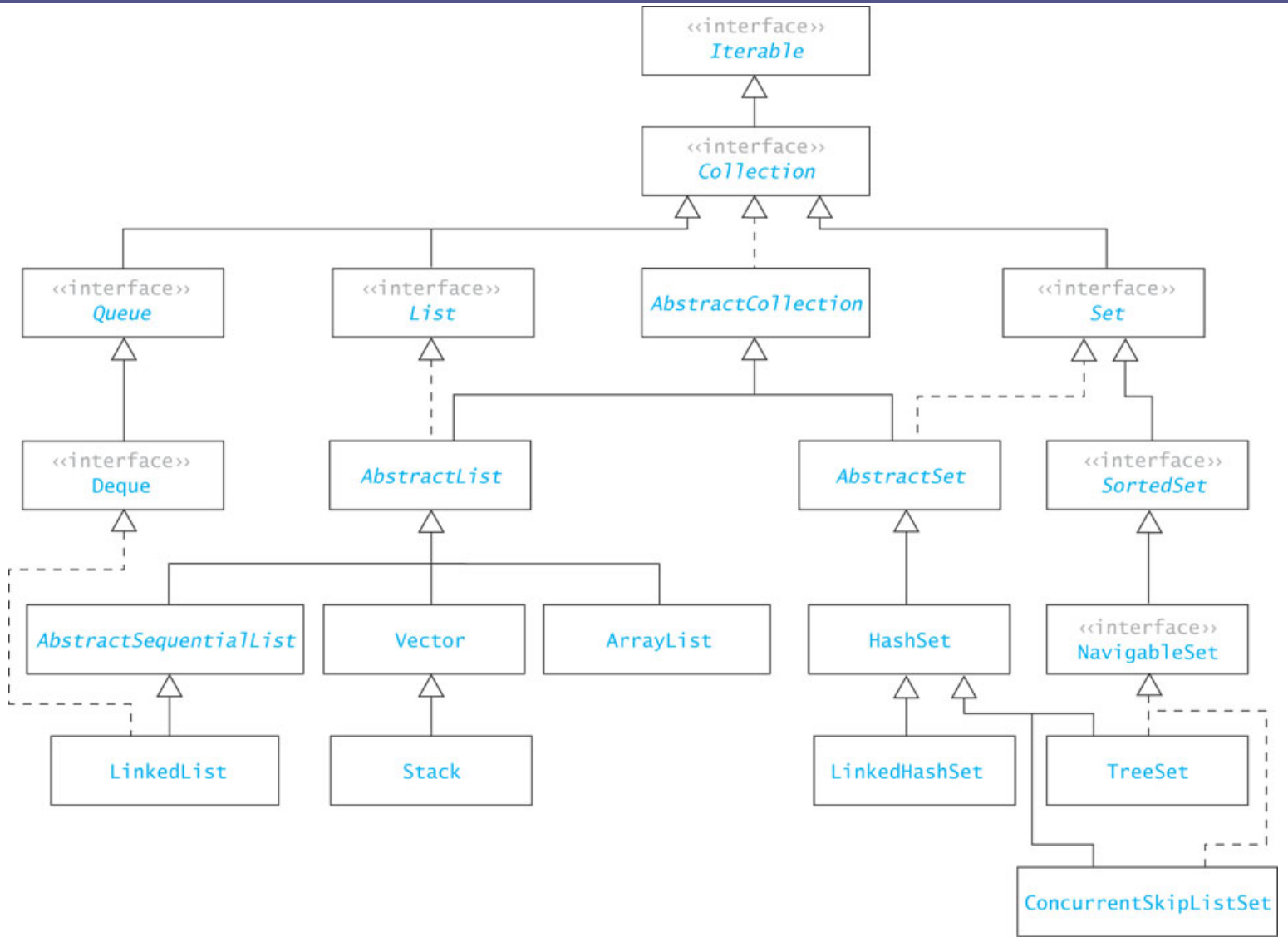
Class `LinkedList` Implements the `Queue` Interface

- The `LinkedList` class provides methods for inserting and removing elements at either end of a double-linked list, which means all `Queue` methods can be implemented easily
- The Java `LinkedList` class implements the `Queue` interface

```
Queue<String> names = new LinkedList<String>();
```

  - creates a new `Queue` reference, `names`, that stores references to `String` objects

The Collection Framework



Implementing the Queue Interface

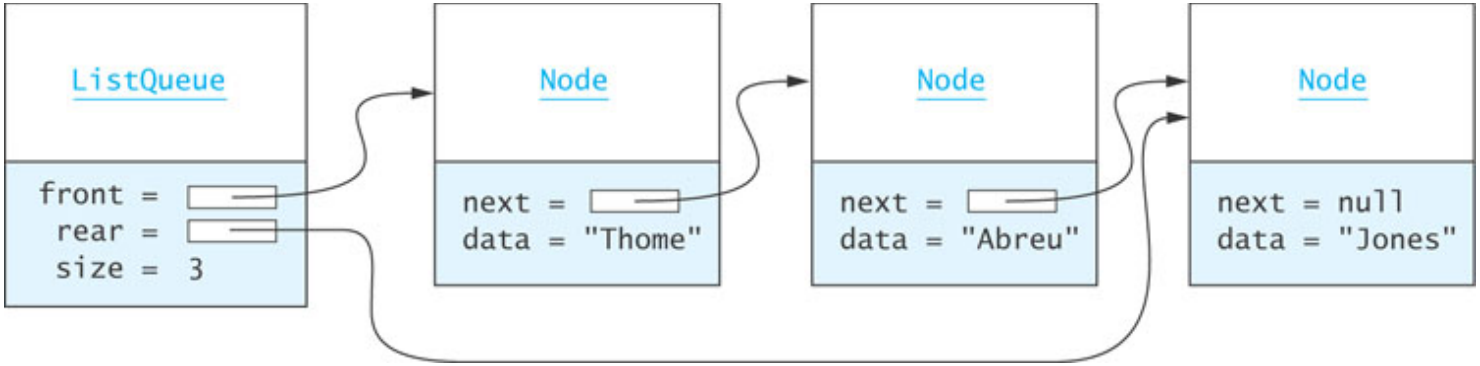
Section 4.7

Using a Double-Linked List to Implement the `Queue` Interface

- Insertion and removal from either end of a double-linked list is O(1) so either end can be the front (or rear) of the queue
- Java designers decided to make the head of the linked list the front of the queue and the tail the rear of the queue
- Problem: If a `LinkedList` object is used as a queue, it will be possible to apply other `LinkedList` methods in addition to the ones required and permitted by the `Queue` interface
- Solution: Create a new class with a `LinkedList` component and then code (by delegation to the `LinkedList` class) only the public methods required by the `Queue` interface

Using a Single-Linked List to Implement a `Queue`

- Insertions are at the rear of a queue and removals are from the front
- We need a reference to the last list node so that insertions can be performed at O(1)
- The number of elements in the queue is changed by methods insert and remove



Using a Single-Linked List to Implement a Queue


```
import java.util.*;
/** Implements the Queue interface using a single-linked
   list.
*   @author Koffman & Wolfgang * */
public class ListQueue < E >
    extends AbstractQueue < E >
    implements Queue < E > {

  // Data Fields
  /** Reference to front of queue. */
  private Node < E > front;

  /** Reference to rear of queue. */
  private Node < E > rear;
```

Using a Single-Linked List to Implement a Queue


```
/** Size of queue. */
private int size;

/** A Node is the building block for a single-linked list.
 */
private static class Node < E > {
  // Data Fields
  /** The reference to the data. */
  private E data;

  /** The reference to the next node. */
  private Node next;
```

Using a Single-Linked List to Implement a Queue


```
  // Constructors
  /** Creates a new node with a null next field.
      @param dataItem The data stored
   */
  private Node(E dataItem) {
    data = dataItem;
    next = null;
  }
  /** Creates a new node that references another node.
      @param dataItem The data stored
      @param nodeRef The node referenced by new node
   */
  private Node(E dataItem, Node < E > nodeRef) {
    data = dataItem;
    next = nodeRef;
  }
} //end class Node
```

Using a Single-Linked List to Implement a Queue


```
// Methods
/** Insert an item at the rear of the queue.
    post: item is added to the rear of the queue.
    @param item The element to add
    @return true (always successful)   */
public boolean offer(E item) {
  // Check for empty queue.
  if (front == null) {
    rear = new Node < E > (item);
    front = rear;
  }
  else {
          …
```

Using a Single-Linked List to Implement a Queue


```
else {
    // Allocate a new node at end, store item in
    // it, and
    // link it to old end of queue.
          ?????
    }
  size++;
  return true;
}
```

Using a Single-Linked List to Implement a Queue


```
/** Remove the entry at the front of the queue and return it
    if the queue is not empty.
    post: front references item that was second in the queue.
    @return The item removed if successful, or null if not
*/
public E poll() {
  E item = peek(); // Retrieve item at front.
  if (item == null)
    return null;
  // Remove item at front.
  front = front.next;
  size--;
  return item; // Return data at front of queue.
}
```

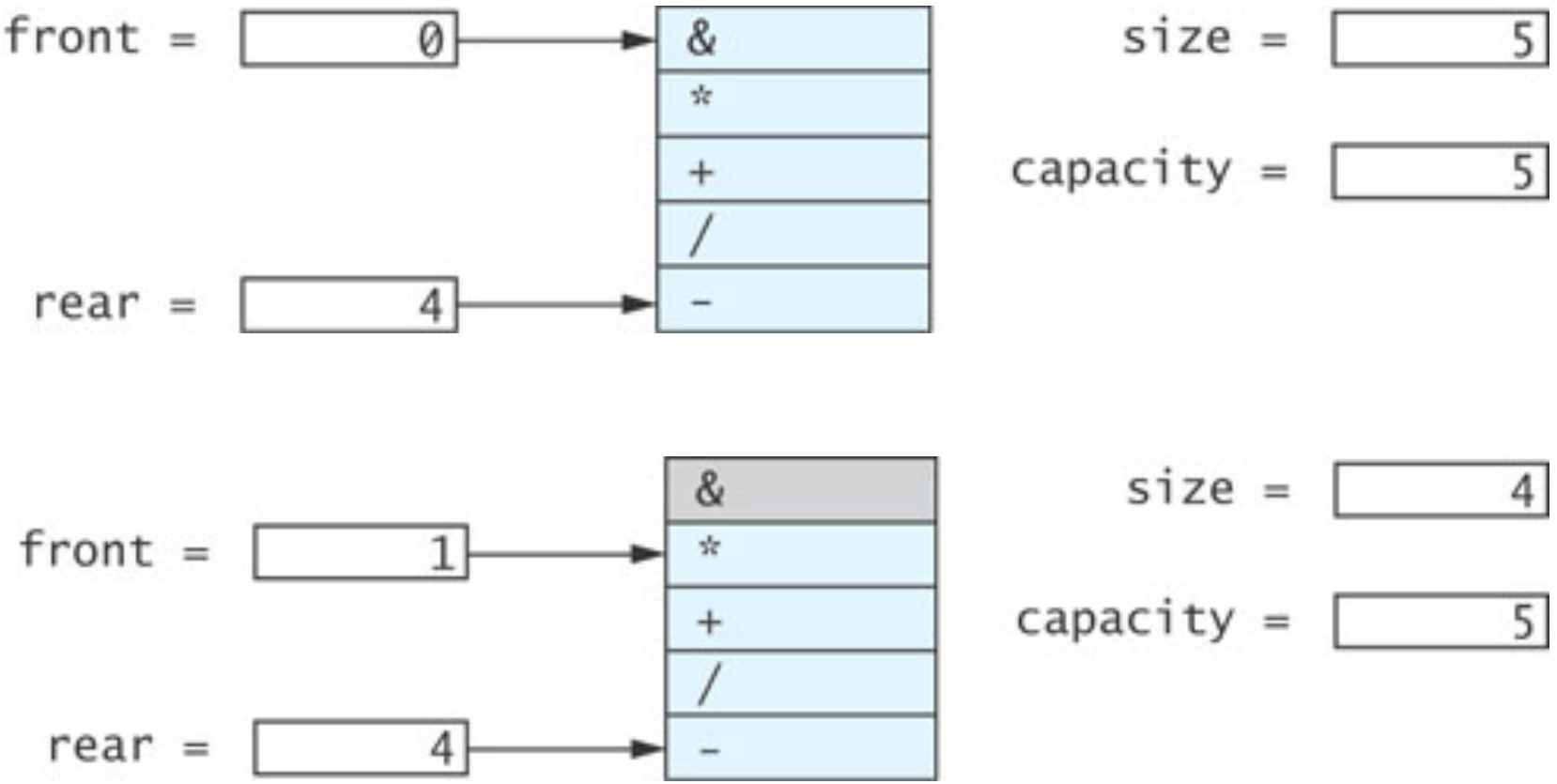
Using a Single-Linked List to Implement a Queue


```
  /** Return the item at the front of the queue
  without removing it.
      @return The item at the front of the queue if
  successful;
                return null if the queue is empty
   */
  public E peek() {
    if (size == 0)
      return null;
    else
      return front.data;
  }
}
```

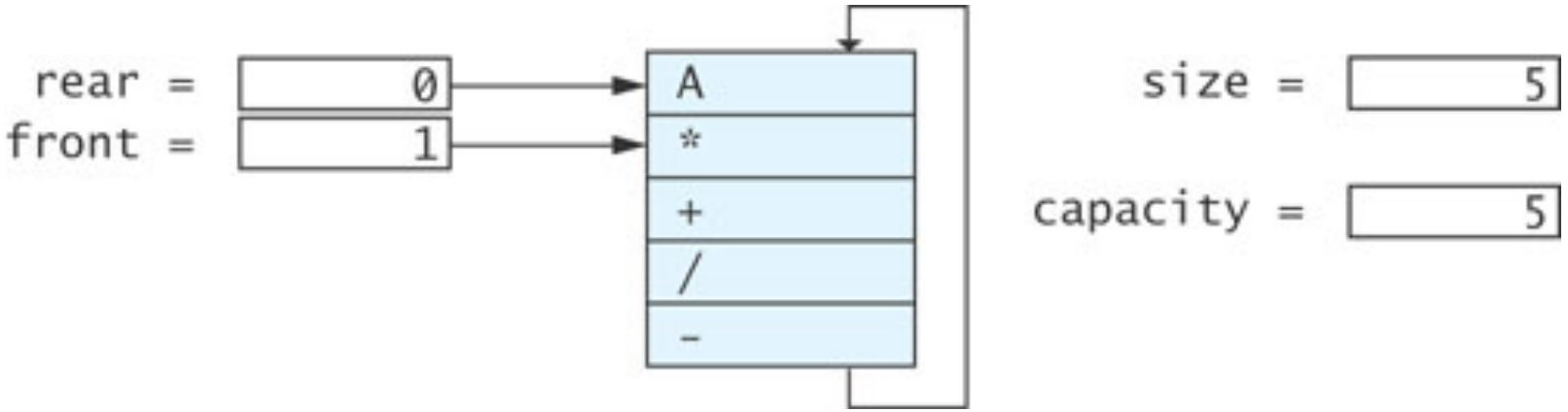
Implementing a Queue Using a Circular Array

- The time efficiency of using a single- or double-linked list to implement a queue is acceptable
- However, there are some space inefficiencies
- Storage space is increased when using a linked list due to references stored in the nodes
- Array Implementation
  - Insertion at rear of array is constant time O(1)
  - Removal from the front is linear time O(*n*)
  - Removal from rear of array is constant time O(1)
  - Insertion at the front is linear time O(*n*)
- We can avoid these inefficiencies in an array

Implementing a Queue Using a Circular Array (cont.)



Implementing a Queue Using a Circular Array (cont.)



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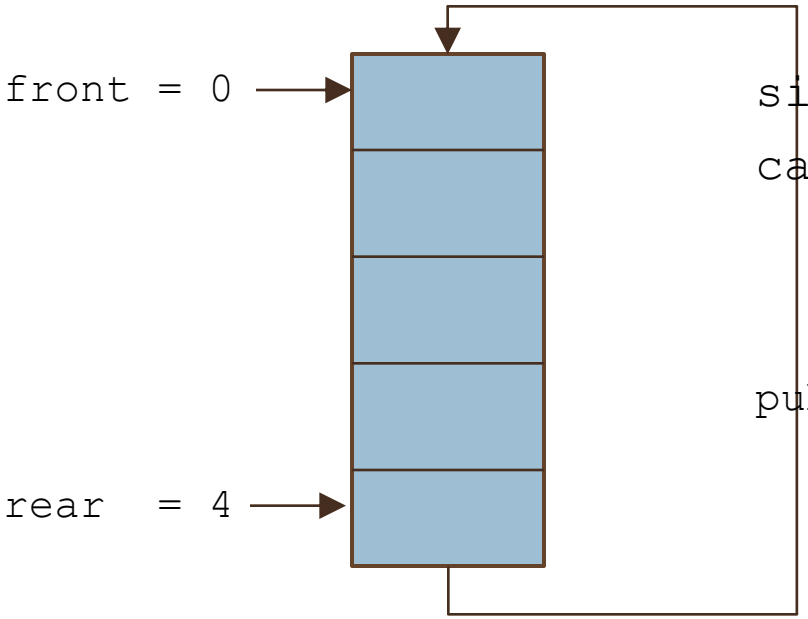
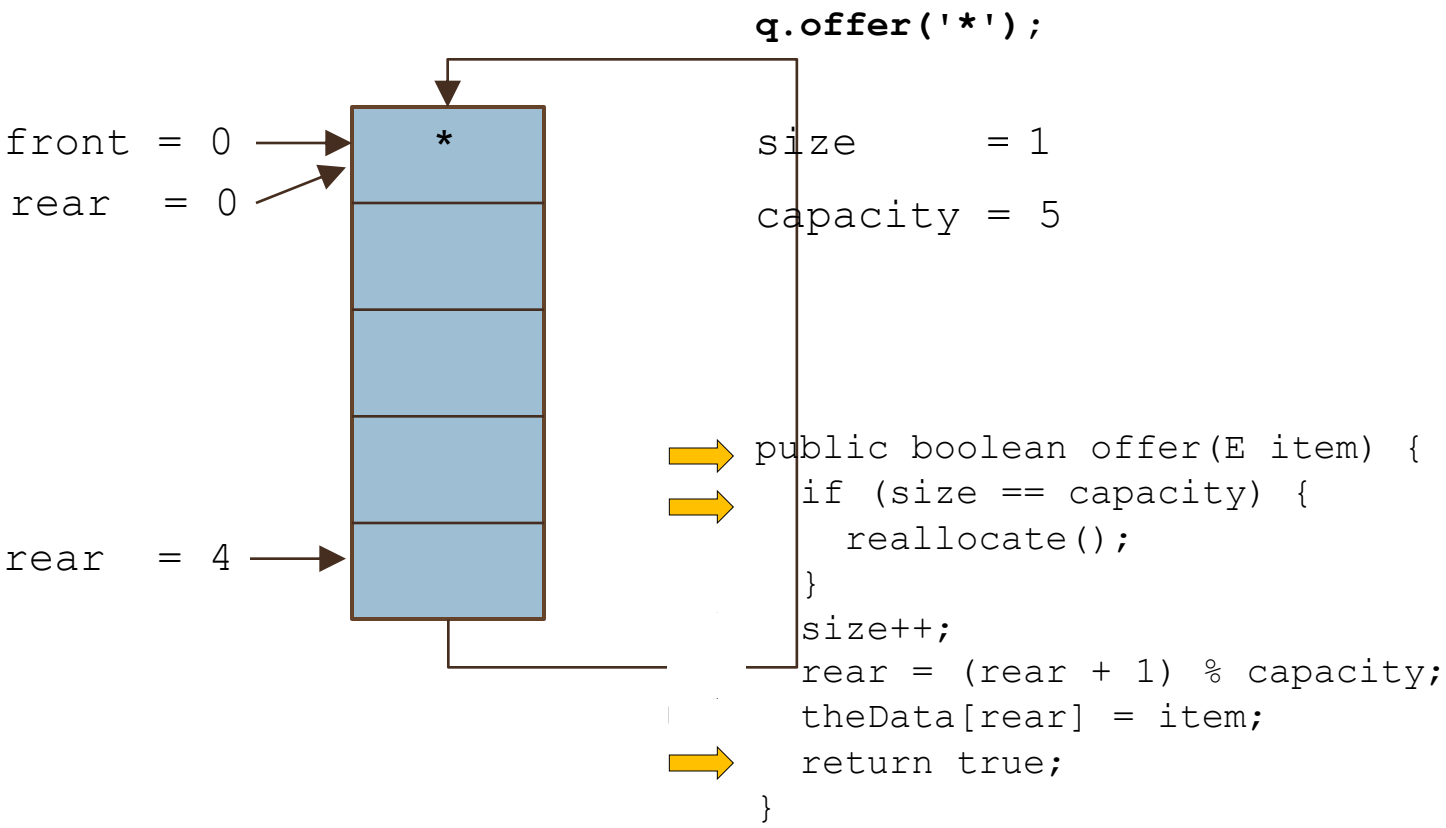



```
ArrayQueue q = new ArrayQueue(5);
```

```
size     = 0
capacity = 5
```

```
public ArrayQueue(int initCapacity) {
   capacity = initCapacity;
   theData = (E[])new Object[capacity];
   front = 0;
   rear = capacity - 1;
   size = 0;
}
```

Implementing a Queue Using a Circular Array (cont.)



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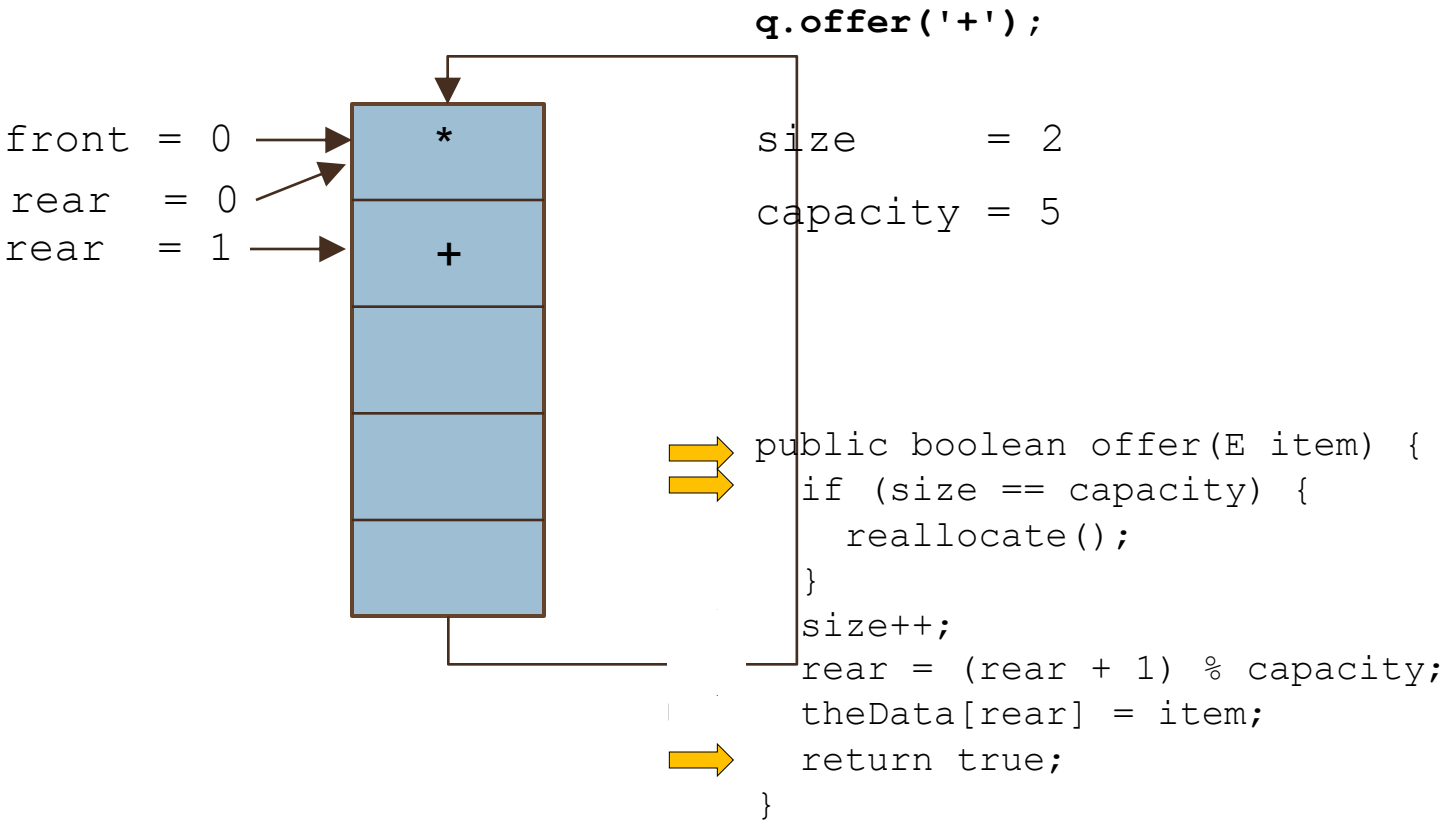

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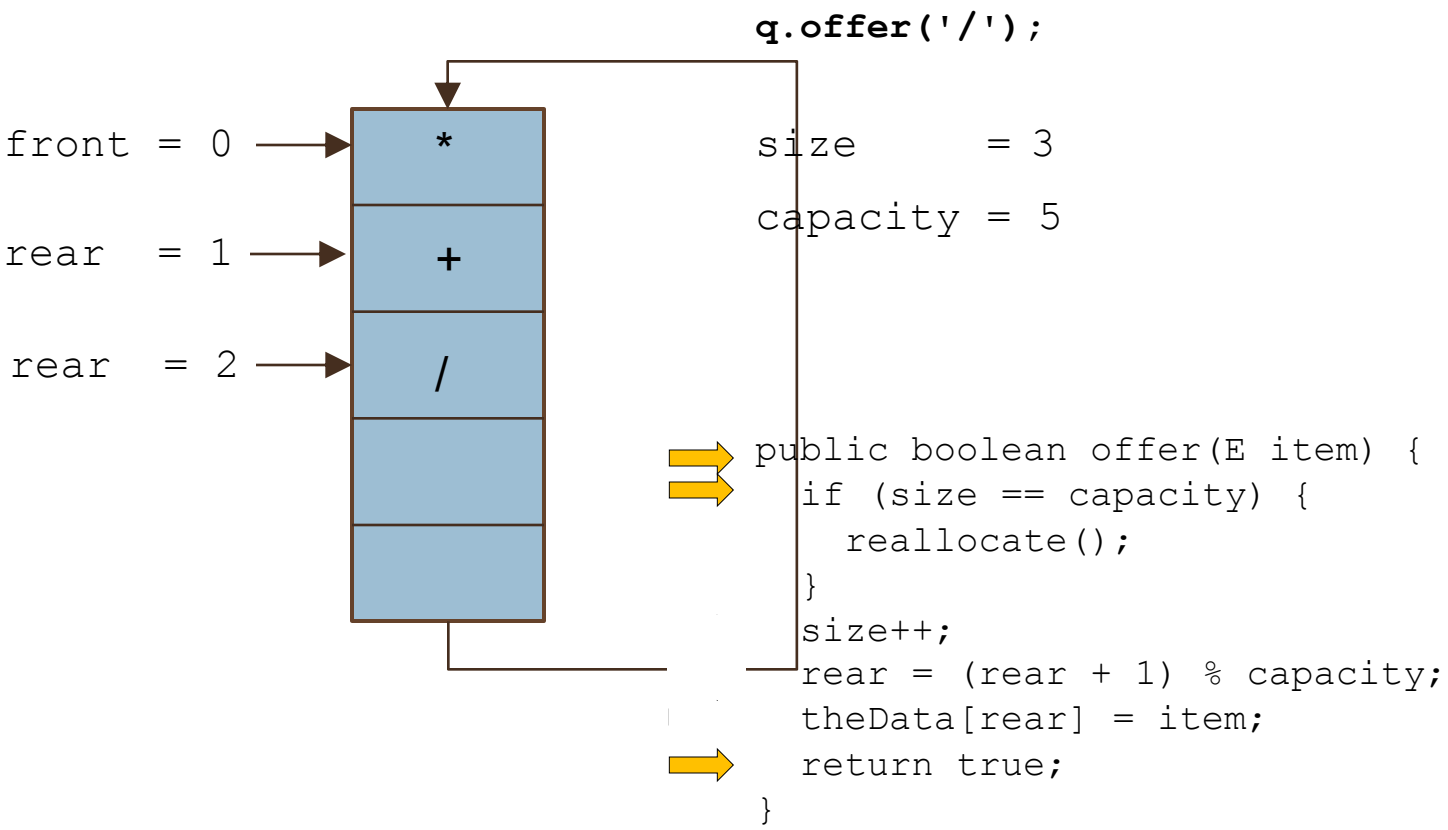
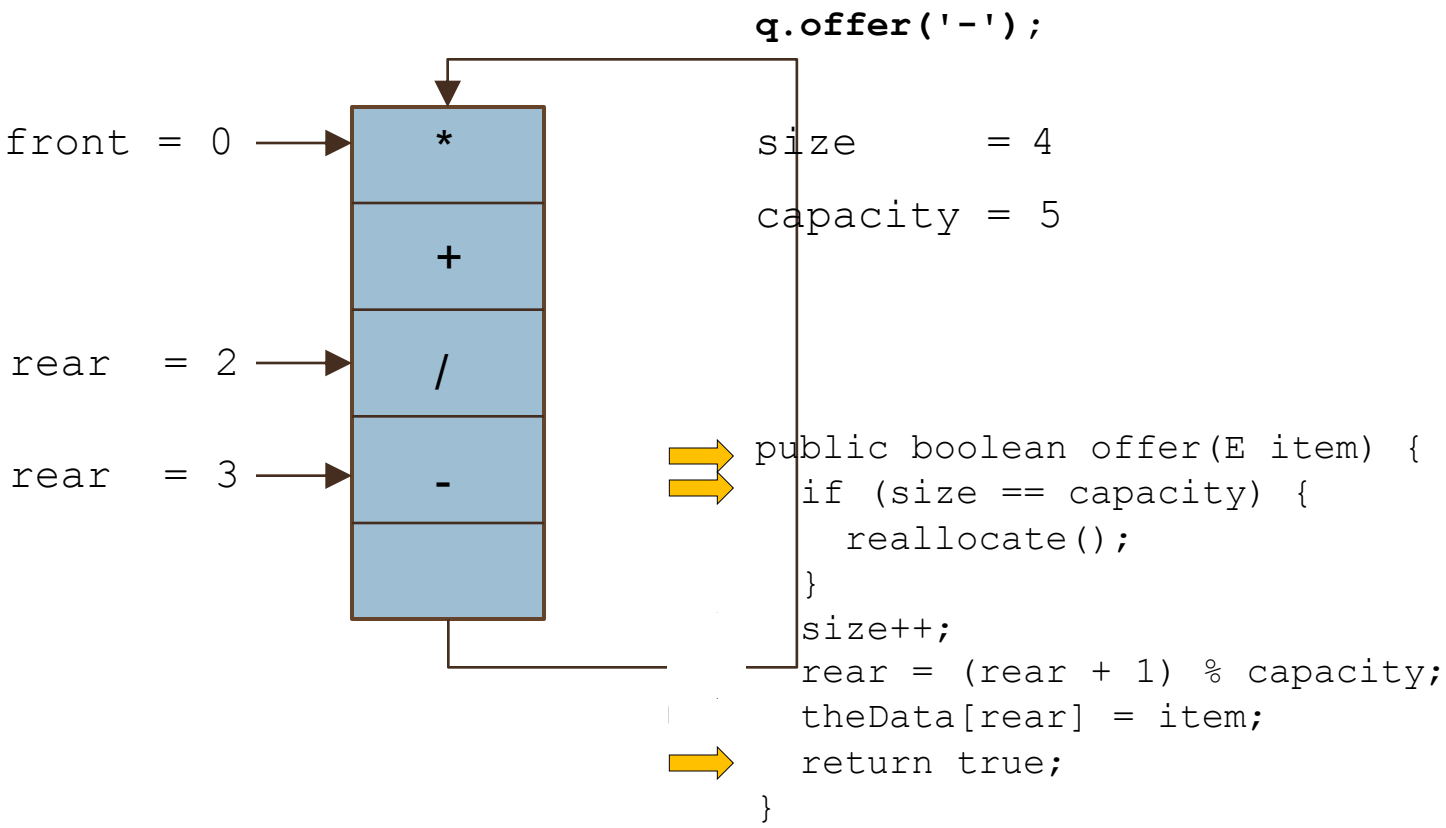
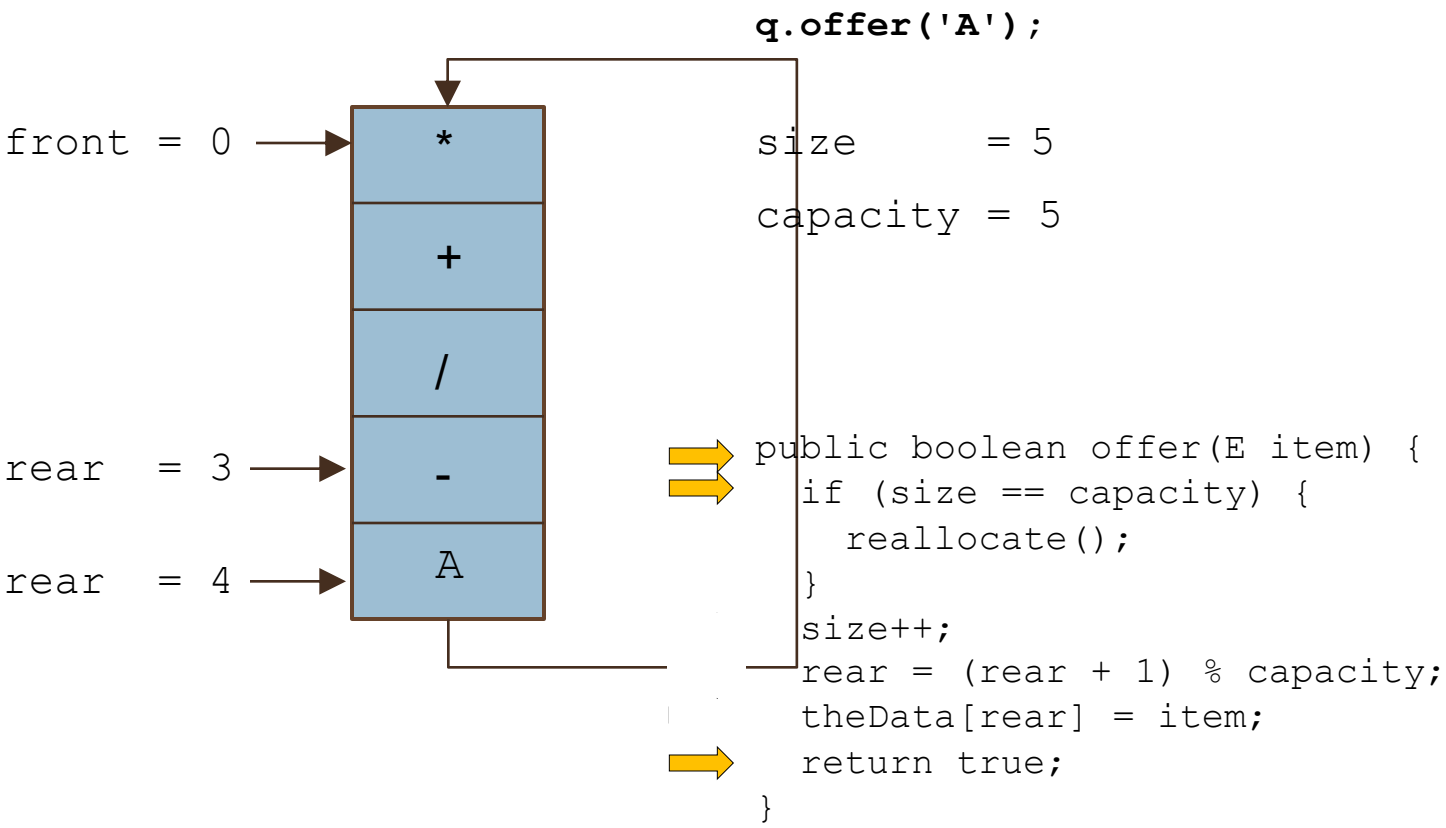


Implementing a Queue Using a Circular Array (cont.)



Implementing a Queue Using a Circular Array (cont.)



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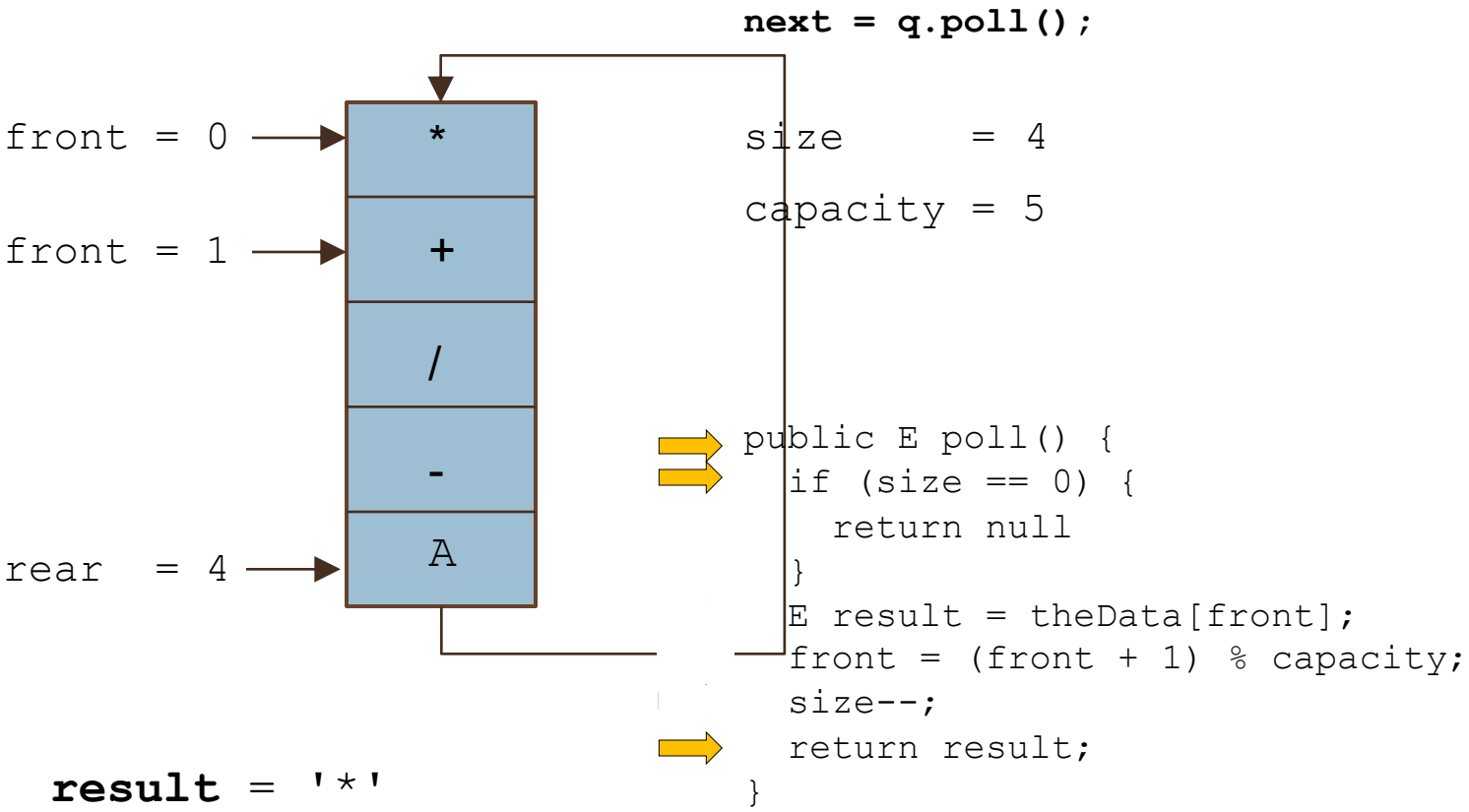
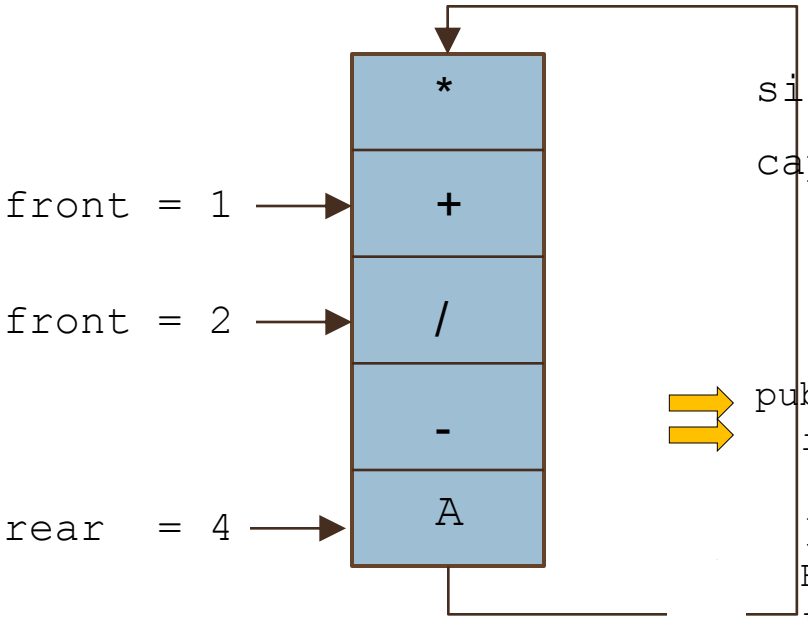


Implementing a Queue Using a Circular Array (cont.)



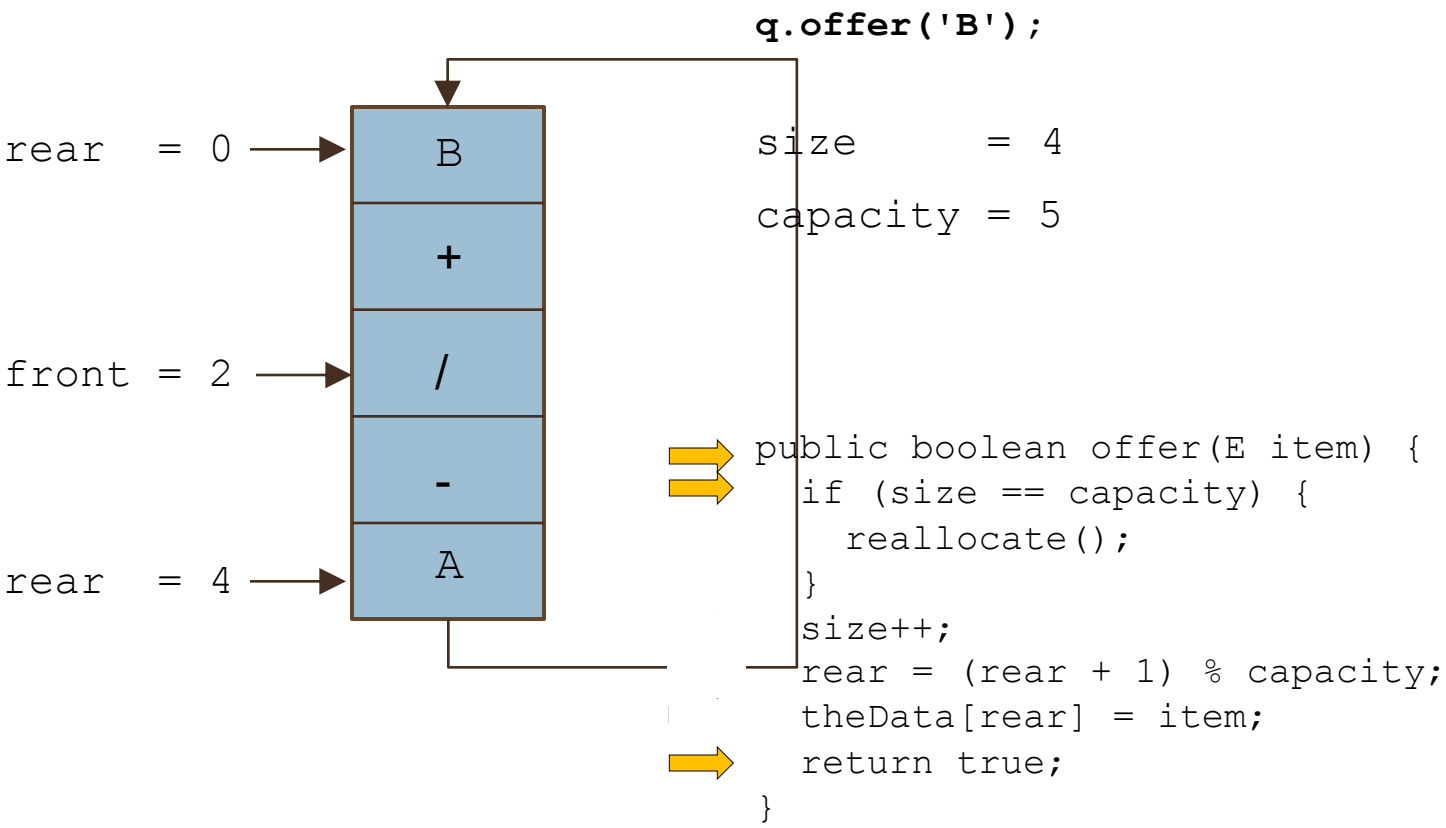

```
next = q.poll();

size     = 3
capacity = 5

public E poll() {
  if (size == 0) {
    return null
  }
  E result = theData[front];
  front = (front + 1) % capacity;
  size--;
  return result;
}
```

result = '+'

Implementing a Queue Using a Circular Array (cont.)



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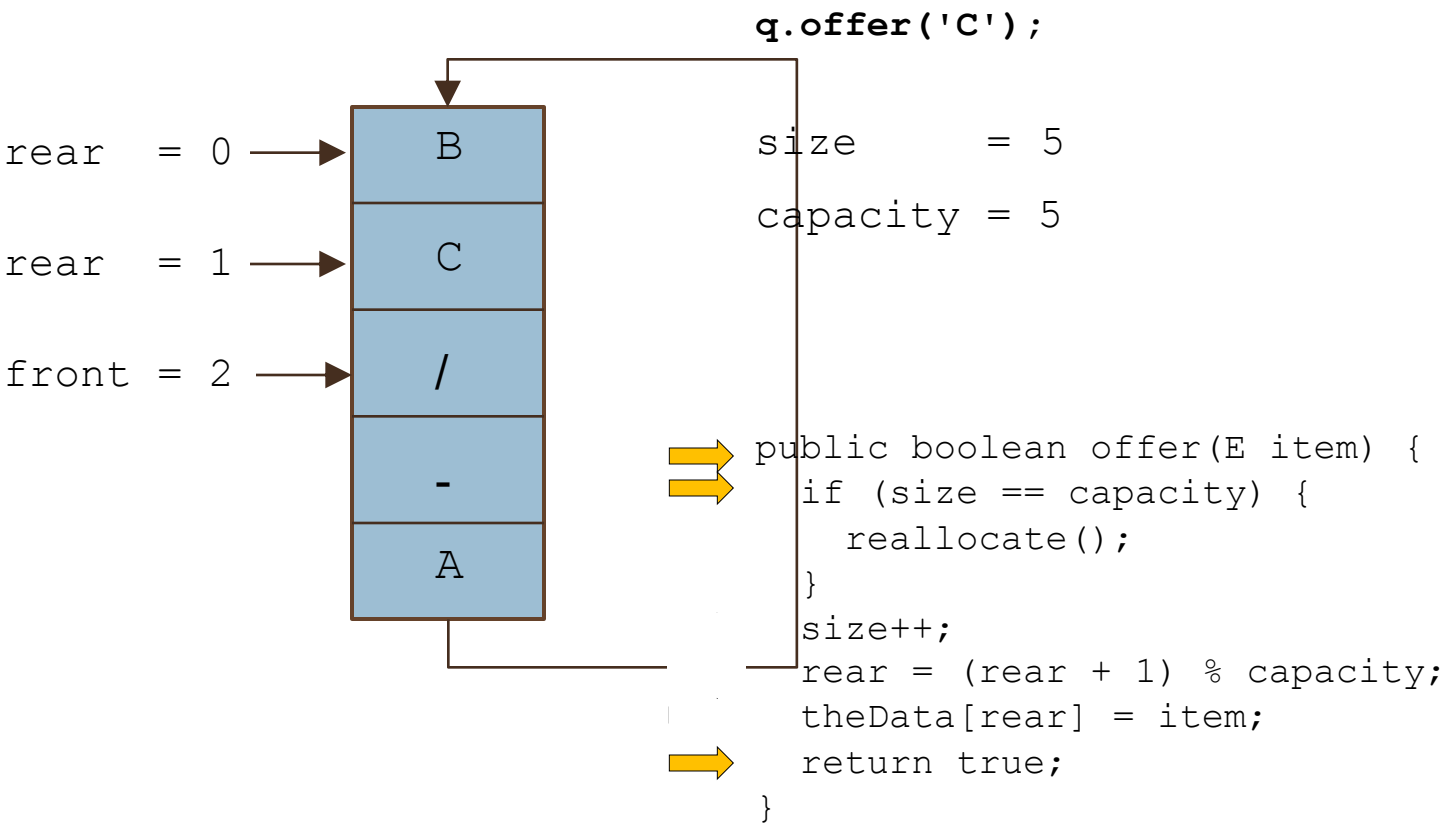
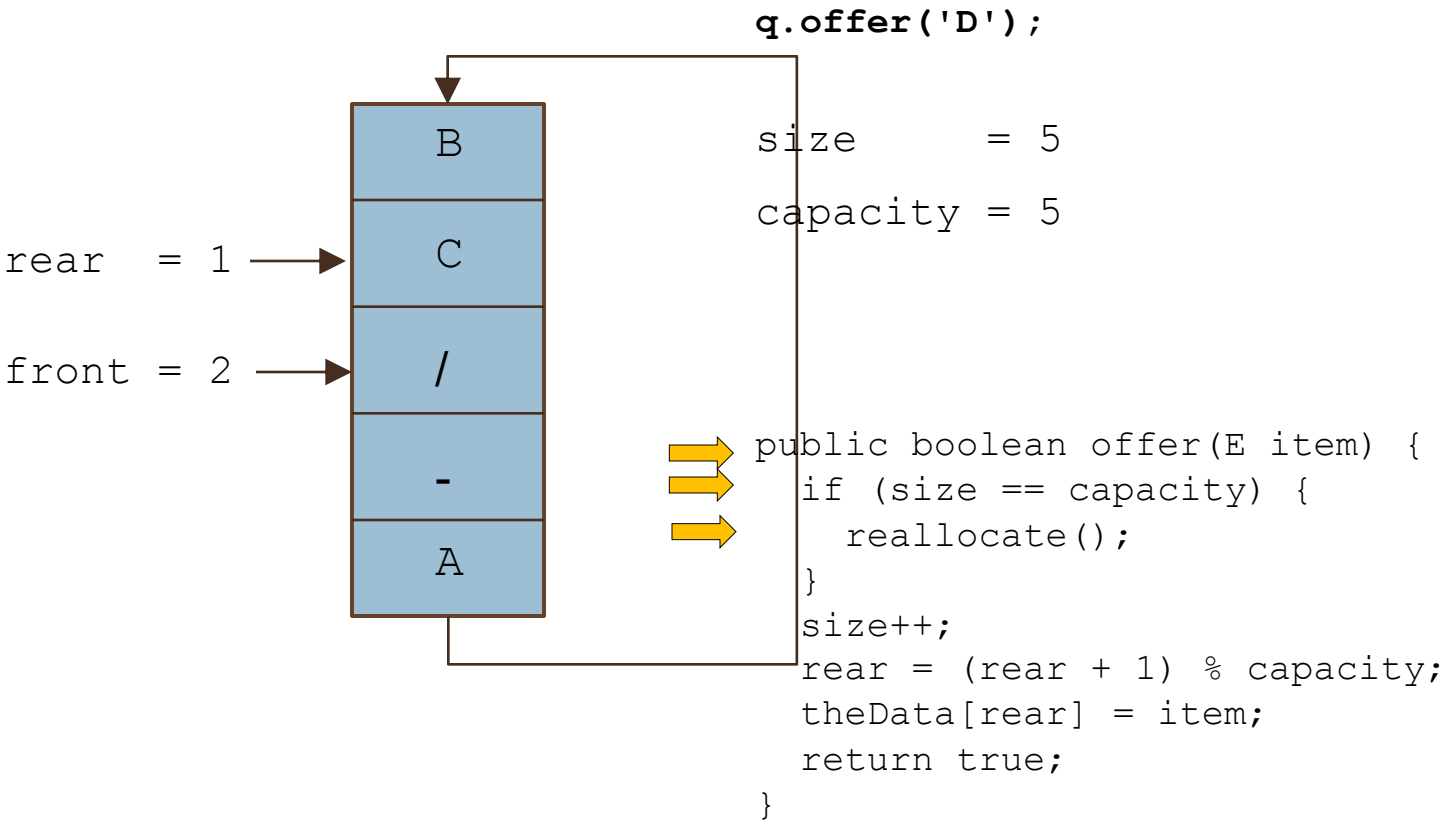
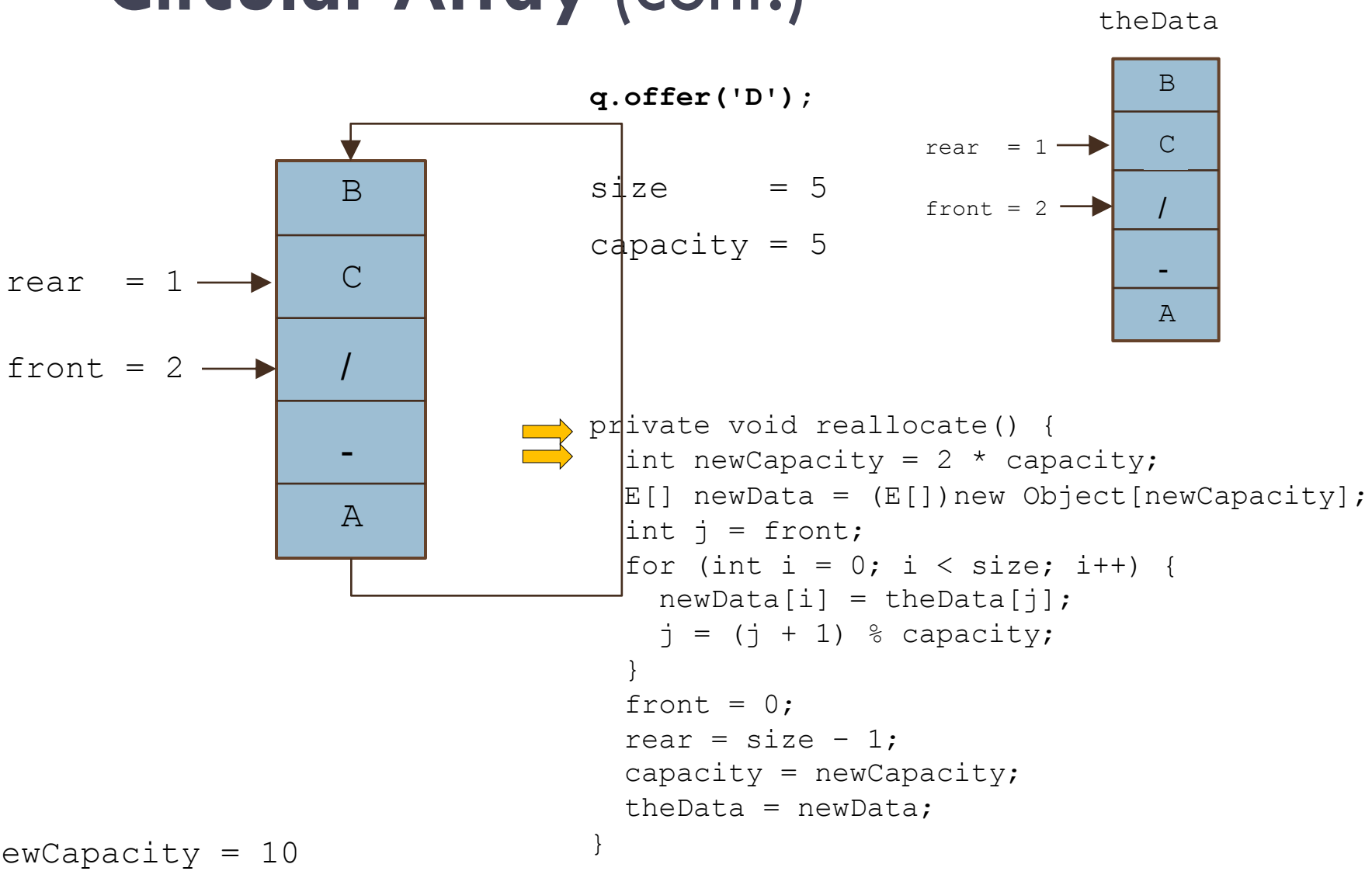


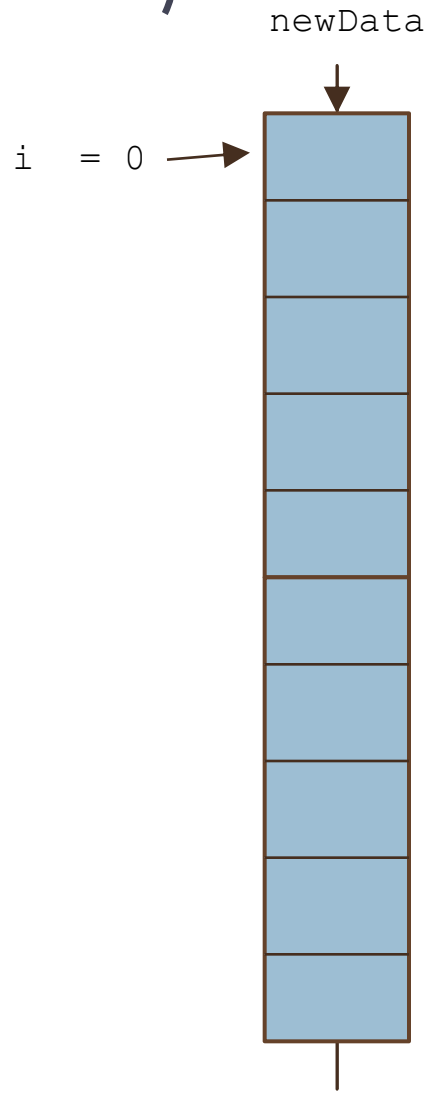
Implementing a Queue Using a Circular Array (cont.)



Implementing a Queue Using a Circular Array (cont.)



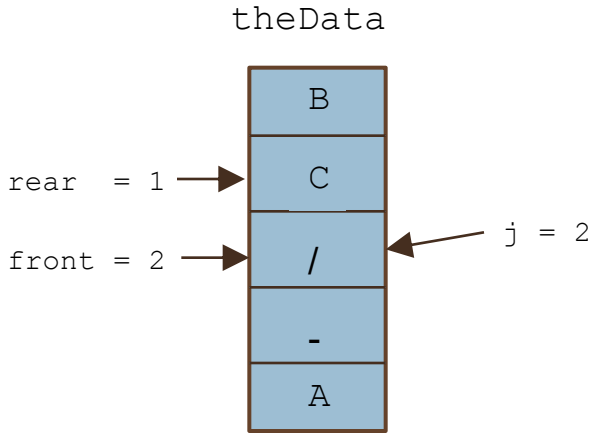
Implementing a Queue Using a Circular Array (cont.)



q.offer('D');

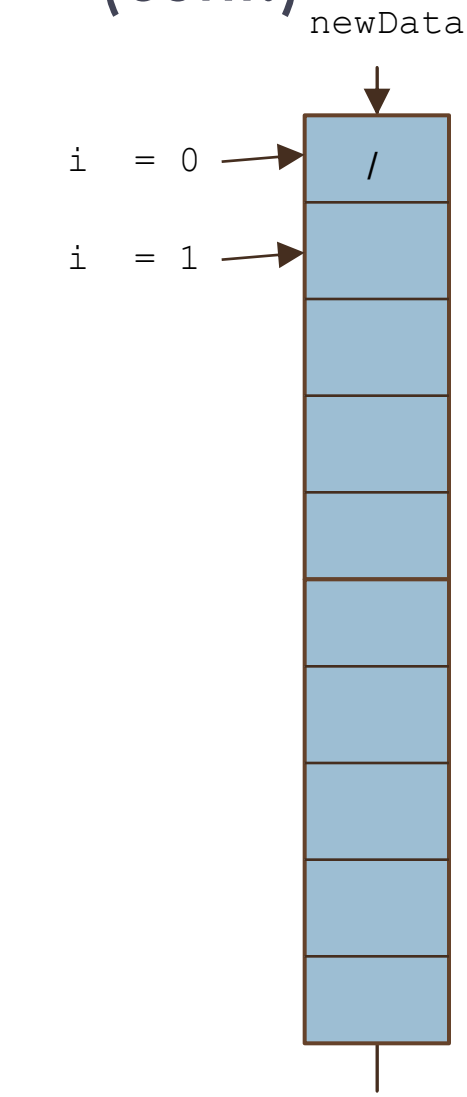
size = 5

capacity = 5




```
private void reallocate() {
  int newCapacity = 2 * capacity;
  E[] newData = (E[])new Object[newCapacity];
  int j = front;
  for (int i = 0; i < size; i++) {
    newData[i] = theData[j];
    j = (j + 1) % capacity;
  }
  front = 0;
  rear = size - 1;
  capacity = newCapacity;
  theData = newData;
}
```

Implementing a Queue Using a Circular Array (cont.)



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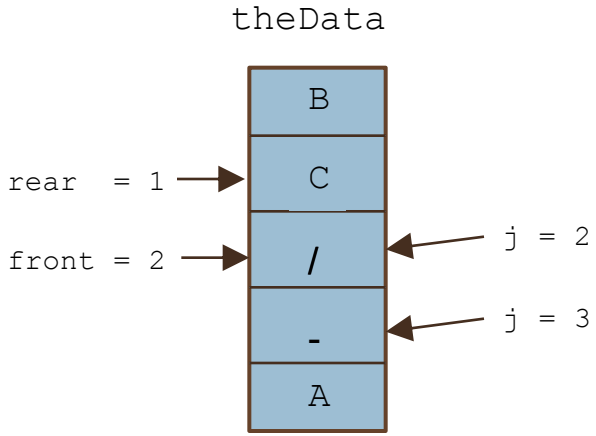


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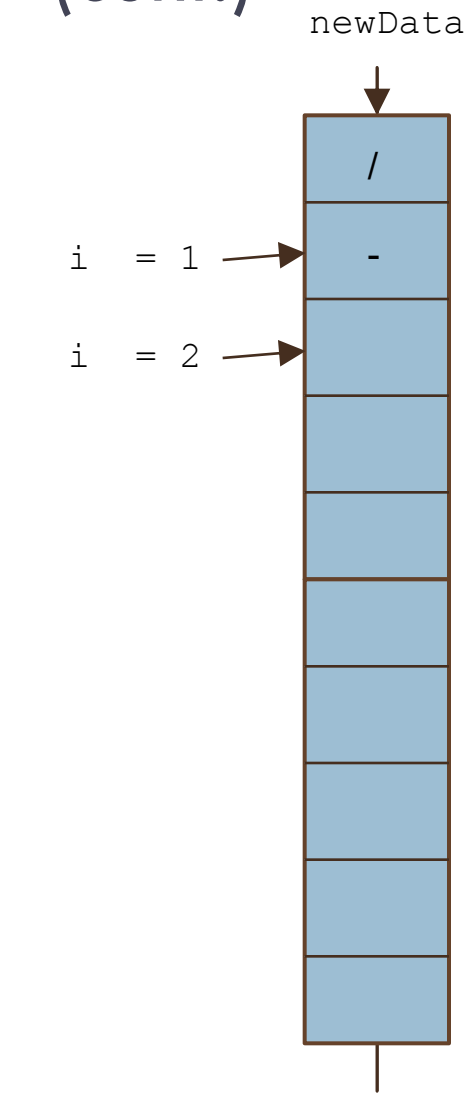
Implementing a Queue Using a Circular Array (cont.)



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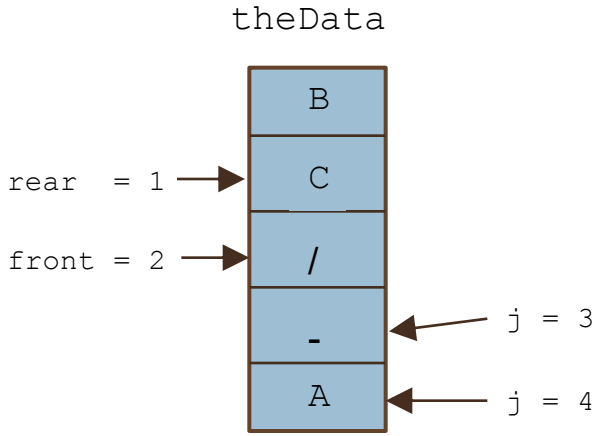
size = 5

capacity = 5

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    j = (j + 1) % capacity;
  }
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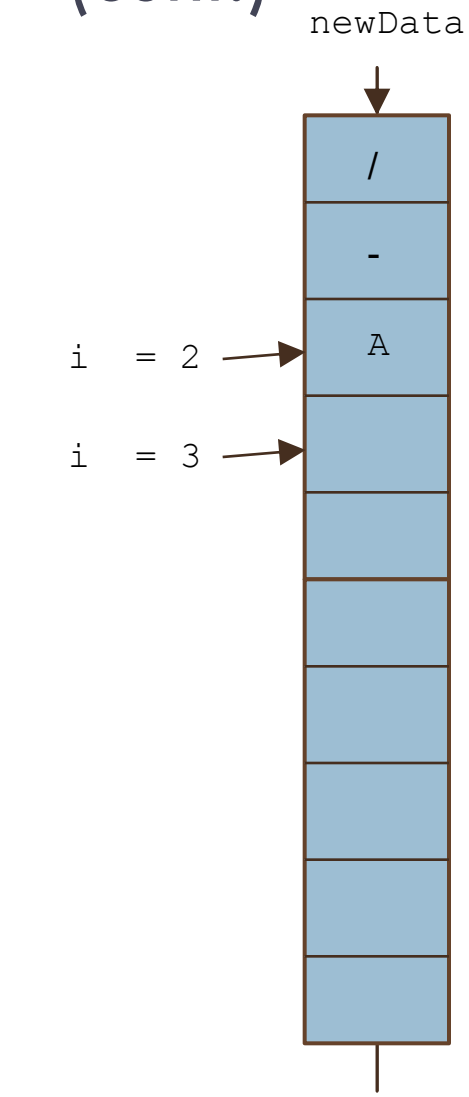
  rear = size - 1;
  capacity = newCapacity;
  theData = newData;
}
```

Implementing a Queue Using a Circular Array (cont.)



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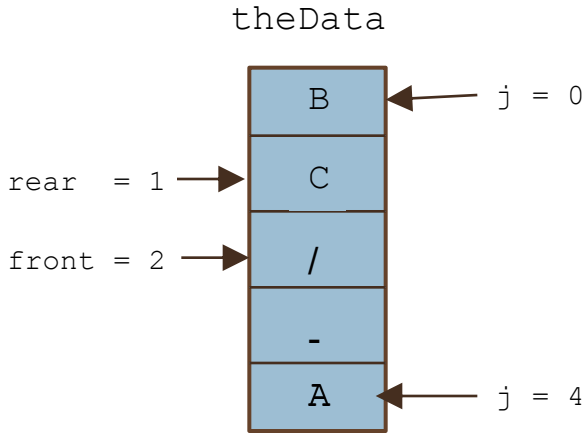


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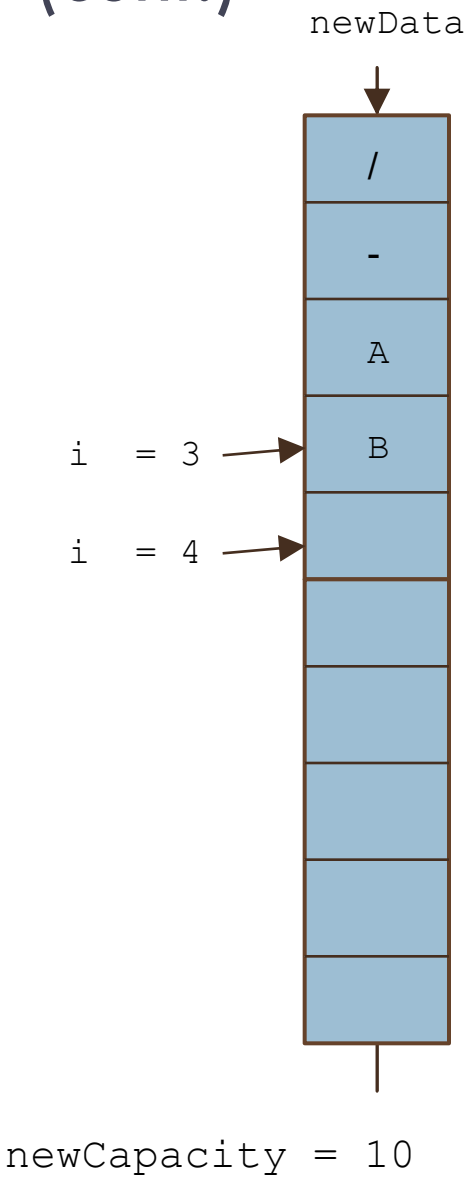
Implementing a Queue Using a Circular Array (cont.)



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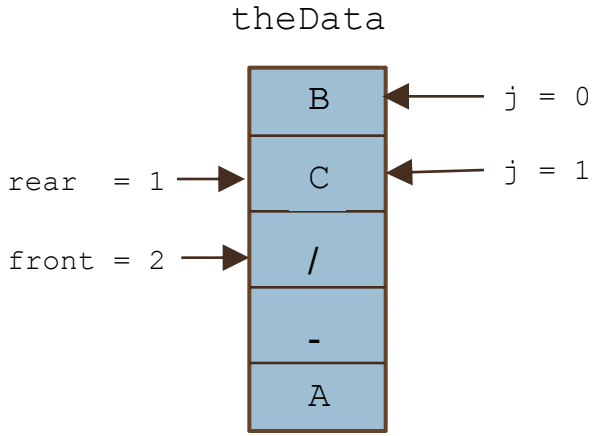


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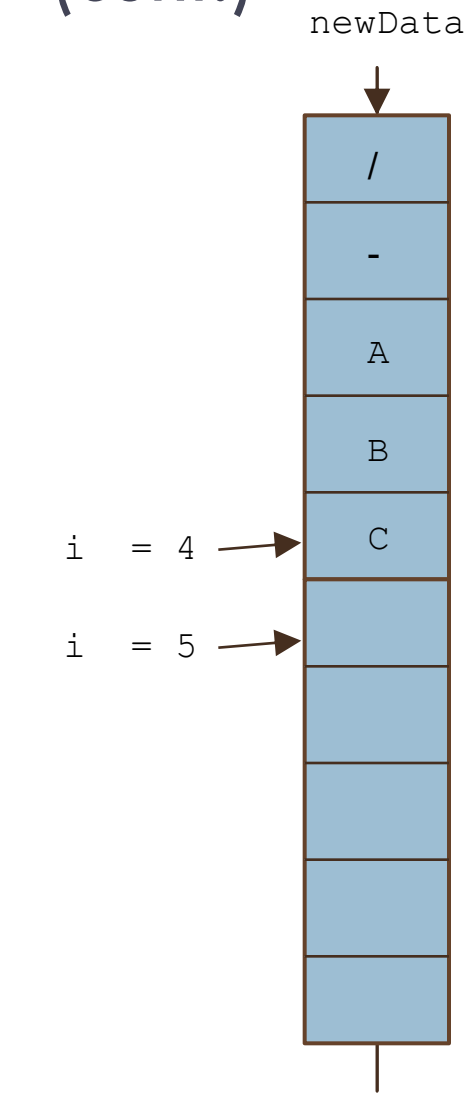
Implementing a Queue Using a Circular Array (cont.)



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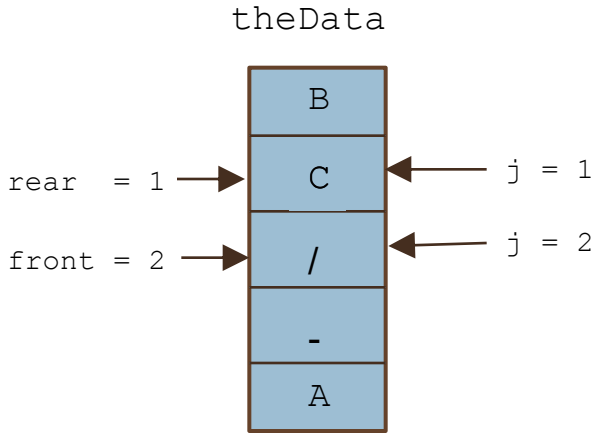


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```
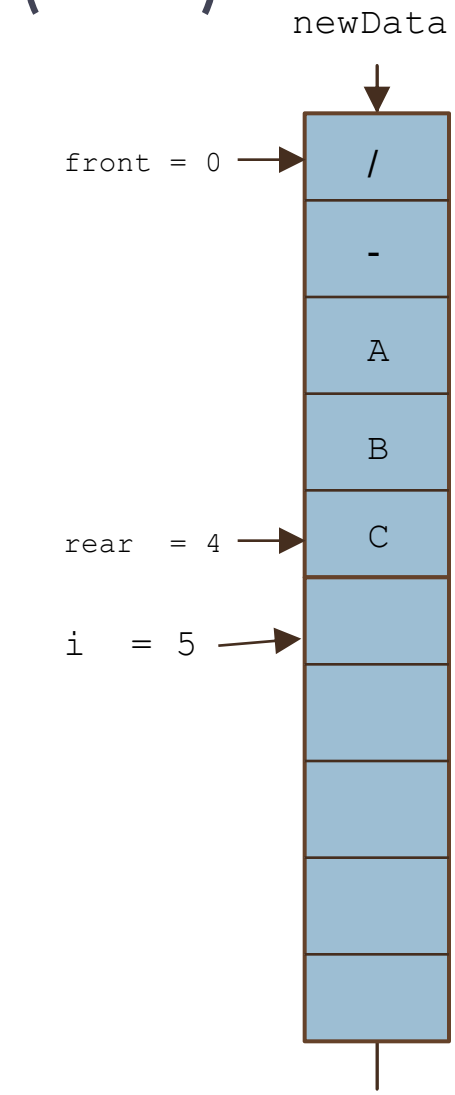
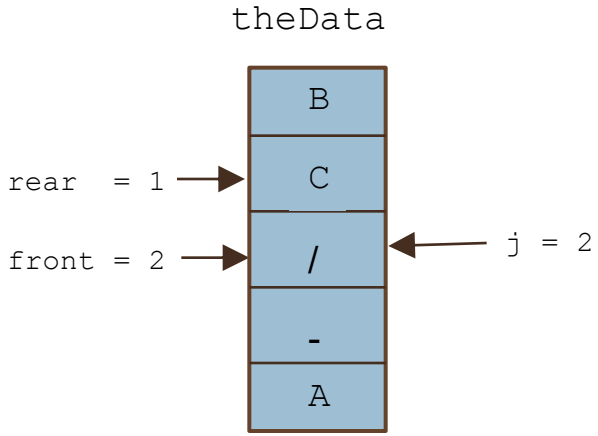

Implementing a Queue Using a Circular Array (cont.)



q.offer('D');

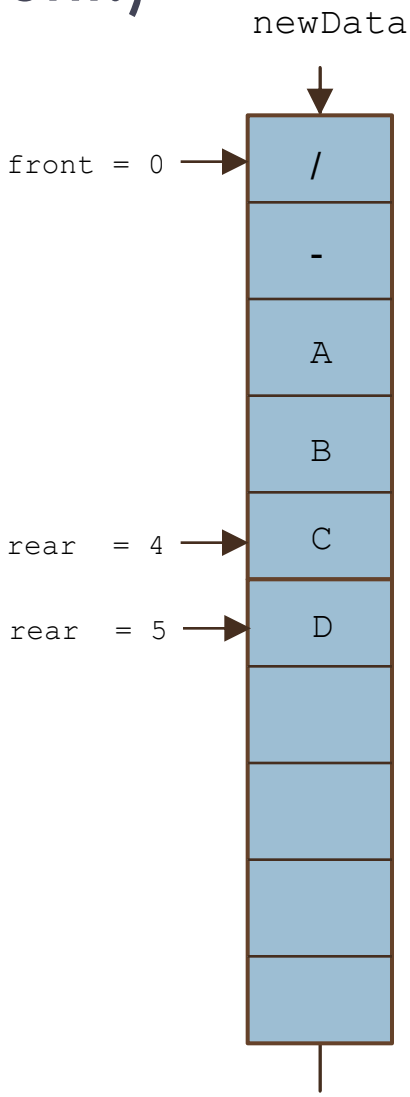
size = 5

capacity = 10




```
private void reallocate() {
  int newCapacity = 2 * capacity;
  E[] newData = (E[])new Object[newCapacity];
  int j = front;
  for (int i = 0; i < size; i++) {
    newData[i] = theData[j];
    j = (j + 1) % capacity;
  }
  front = 0;
  rear = size - 1;
  capacity = newCapacity;
  theData = newData;
}
```

Implementing a Queue Using a Circular Array (cont.)



q.offer('D');

size = 6

capacity = 10

```
public boolean offer(E item) {
  if (size == capacity) {
    reallocate();
  }
  size++;
  rear = (rear + 1) % capacity;
  theData[rear] = item;
  return true;
}
```

Implementing a Queue Using a Circular Array (cont.)


```
// Public Methods
  /** Inserts an item at the rear of the queue.
      post: item is added to the rear of the queue.
      @param item The element to add
      @return true (always successful)   */
  public boolean offer(E item) {
    if (size == capacity) {
      reallocate();
    }
    size++;
    rear = (rear + 1) % capacity;
    theData[rear] = item;
    return true;
  }
```

Implementing a Queue Using a Circular Array (cont.)


```
/** Removes the entry at the front of the queue and returns it
      if the queue is not empty.
      post: front references item that was second in the queue.
      @return The item removed if successful or null if not
   */
  public E poll() {
    if (size == 0) {
      return null;
    }
    E result = theData[front];
    front = (front + 1) % capacity;
    size--;
    return result;
  }
```

Comparing the Three Implementations

- Computation time
  - All three implementations (double-linked list, single-linked list, circular array) are comparable in terms of computation time
  - All operations are O(1) regardless of implementation
  - Although reallocating an array is O(*n*), its is amortized over *n* items, so the cost per item is O(1)

Comparing the Three Implementations (cont.)

- Storage
  - Linked-list implementations require more storage due to the extra space required for the links
    - Each node for a single-linked list stores two references (one for the data, one for the link)
    - Each node for a double-linked list stores three references (one for the data, two for the links)
  - A double-linked list requires 1.5 times the storage of a single-linked list
  - A circular array that is filled to capacity requires half the storage of a single-linked list to store the same number of elements,
  - but a recently reallocated circular array is half empty, and requires the same storage as a single-linked list

The Deque Interface

Section 4.8

`Deque` **Interface**

- A deque (pronounced "deck") is short for double-ended queue
- A double-ended queue allows insertions and removals from both ends
- The Java Collections Framework provides two implementations of the `Deque` interface
  - `ArrayDeque`
  - `LinkedList`
- `ArrayDeque` uses a resizable circular array, but (unlike `LinkedList`) does not support indexed operations
- `ArrayDeque` is the recommended implementation

Deque **Interface** (cont.)

Method	Behavior
`boolean offerFirst(E item)`	Inserts `item` at the front of the deque. Returns **`true`** if successful; returns **`false`** if the item could not be inserted.
`boolean offerLast(E item)`	Inserts `item` at the rear of the deque. Returns **`true`** if successful; returns **`false`** if the item could not be inserted.
`voidaddFirst(E item)`	Inserts `item` at the front of the deque. Throws an exception if the item could not be inserted.
`voidaddLast(E item)`	Inserts `item` at the rear of the deque. Throws an exception if the item could not be inserted.
`E pollFirst()`	Removes the entry at the front of the deque and returns it; returns **`null`** if the deque is empty.
`E pollLast()`	Removes the entry at the rear of the deque and returns it; returns **`null`** if the deque is empty.
`E removeFirst()`	Removes the entry at the front of the deque and returns it if the deque is not empty. If the deque is empty, throws a `NoSuchElementException`.
`E removeLast()`	Removes the item at the rear of the deque and returns it. If the deque is empty, throws a `NoSuchElementException`.
`E peekFirst()`	Returns the entry at the front of the deque without removing it; returns **`null`** if the deque is empty.
`E peekLast()`	Returns the item at the rear of the deque without removing it; returns **`null`** if the deque is empty.
`E getFirst()`	Returns the entry at the front of the deque without removing it. If the deque is empty, throws a `NoSuchElementException`.
`E getLast()`	Returns the item at the rear of the deque without removing it. If the deque is empty, throws a `NoSuchElementException`.
`boolean removeFirstOccurrence(Object item)`	Removes the first occurrence of item in the deque. Returns **`true`** if the item was removed.
`boolean removeLastOccurrence(Object item)`	Removes the last occurrence of item in the deque. Returns **`true`** if the item was removed.
`Iterator<E> iterator()`	Returns an iterator to the elements of this deque in the proper sequence.
`Iterator<E> descendingIterator()`	Returns an iterator to the elements of this deque in reverse sequential order.

Deque **Example**

Deque Method	Deque d	Effect
`d.offerFirst('b')`	b	'b' inserted at front
`d.offerLast('y')`	by	'y' inserted at rear
`d.addLast('z')`	byz	'z' inserted at rear
`d.addFirst('a')`	abyz	'a' inserted at front
`d.peekFirst()`	abyz	Returns 'a'
`d.peekLast()`	abyz	Returns 'z'
`d.pollLast()`	aby	Removes 'z'
`d.pollFirst()`	by	Removes 'a'

Deque Interface (cont.)

- The Deque interface extends the Queue interface, so it can be used as a queue
- A deque can be used as a stack if elements are pushed and popped from the front of the deque
- Using the Deque interface is preferable to using the legacy Stack class (based on Vector)

Stack Method	Equivalent Deque Method
push(e)	addFirst(e)
pop()	removeFirst()
peek()	peekFirst()
empty()	isEmpty()