BACS2063 Data Structures and Algorithms

Array Implementations of Collection ADTs

Chapter 4

Learning Outcomes

At the end of this chapter, you should be able to

- Implement the ADTs list, stack and queue using arrays.
- Discuss the strengths and weaknesses of using arrays to implement the ADTs.
- Analyze the efficiency of the array implementations of the ADTs

Recall: Creating an ADT

Step 1 Write the ADT specification

- Write an ADT specification which describes the characteristics of that data type and the set of operations for manipulating the data. Should not include any implementation or usage details.

Step 2 Implement the ADT

a. Write a Java interface
   - Include all the operations from the ADT specification

b. Write a Java class
   - This class implements the Java interface from a.
   - Determine how to represent the data
   - Implement all the operations from the interface

Step 3 Use the ADT in a client program or application

Collection ADTs

- An ADT that can store a collection of objects.
- A *linear collection* is a collection that stores its entries in a linear sequence, *e.g.*:
  - List
  - Stack
  - Queue

  They differ in the restrictions they place on how these entries may be added, removed, or accessed

Lists

Lists

- A list provides a way to organize data

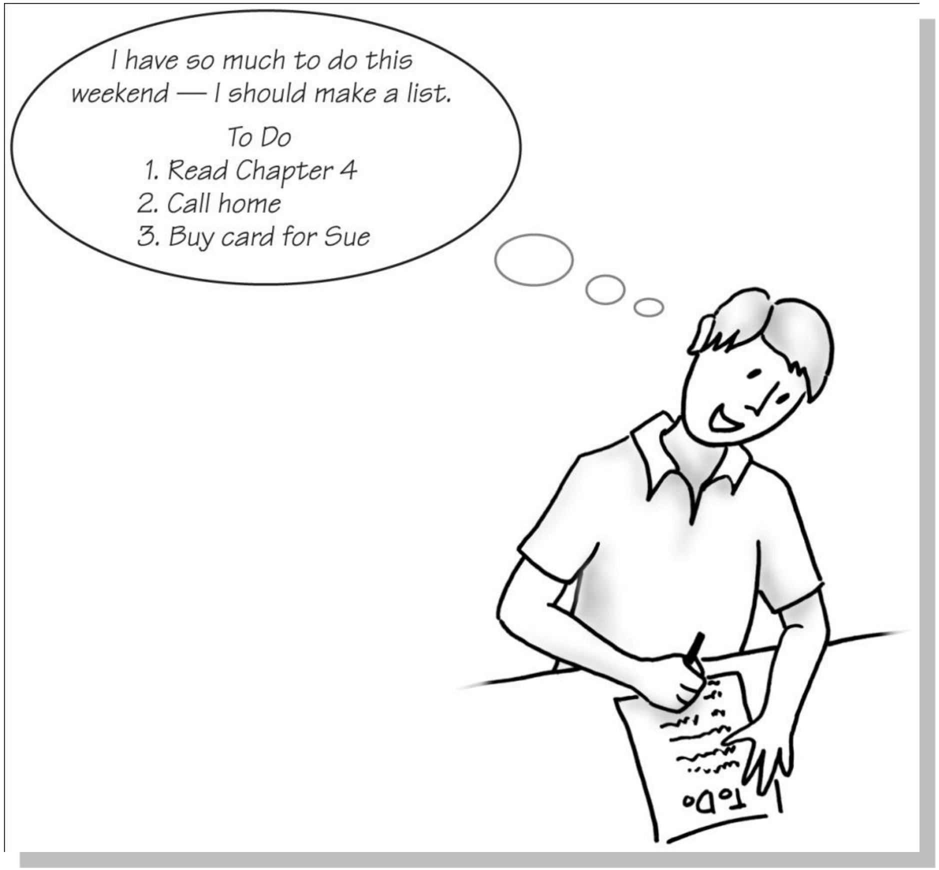


Fig. 4-1 A to-do list.

Operations on Lists

- Add new entry – at end, or anywhere
- Remove an item
- Replace an entry
- Get an entry at a specified position
- Count how many entries
- Check if list is empty, full

Step 1: Write the ADT specification

- Refer to Appendix 4.1 for List ADT specification
  - Note that in this specification, entries in the list have positions that begin with 1 to be consistent with typical lists used in everyday life.
- Remember that at this point,
  - You should not think about how to represent the list in your program or how to implement its operations.
  - Instead, focus on *what* are the operations and *what* the operations do, ***not** how* they do them.
  - *i.e.*, at this point, the list is an abstract data type.

Design Issues

- When you specify an ADT, you need to decide how to handle special / unusual conditions, and the ADT specification should include details on how the special conditions would be handled by the various operations.

Possible Solutions

1. Assume the invalid situations will not occur
2. Ignore the invalid situations
3. Make reasonable assumptions, act in predictable way
4. Return boolean value indicating success or failure of the operation
5. Throw an exception

Possible Solutions #1 & 2 - Do Nothing!

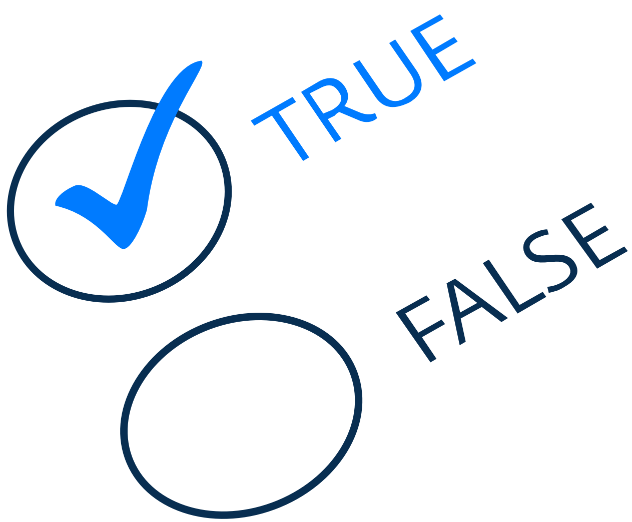
- Assume the invalid situations will not occur
- Ignore the invalid situations

Possible Solutions #3 – Make Assumptions !

- Make reasonable assumptions, act in predictable way

Possible Solutions #4
- Return Boolean Value!

- Return boolean value indicating success or failure of the operation



Possible Solutions #5 - Throw Exception!

- Throw an exception

Step 2: Implement the List ADT (1)

- **Step 2a: Write the Java interface**
  - Contains the method declarations of all the operations listed in the List ADT specification.
  - All the methods are abstract methods.
- Refer to `Chapter4\adt\`
  - **`ListInterface.java`**

Step 2: Implement the List ADT (2)

- **Step 2b: Write the Java class**
  - ❑ Data fields in the Java class:
    - An array – to store the elements of the list
    - An integer variable – to keep track of the current total number of elements in the list

```
T[] array;                  // array of list entries
int numberOfEntries;        // current no. of entries in the list
```

Note: **T** represents the data type of the entries in the list. It will be defined as generic type within the class.

Generic Types (1)

- Used in Java interface and classes which implement *collection* ADTs to specify and constrain the type of objects being stored in the collection.

- The interface name or class name is followed by an identifier enclosed in angle brackets:

```
public interface ListInterface<T>
```

- The identifier **T** – which can be any identifier but usually is a single capital letter – represents the data type within the class definition.

Generic Types (2)

- When you use the class, you supply an actual *type argument* to replace **T**, e.g.:

  ```
  ListInterface<String> taskList;
  ```

- Now, whenever **T** appears as a data type in the definition of `ListInterface`, `String` will be used.

- Note: A generic type *must be a reference type*, not a primitive type.

Using Generic Type in a Java Interface

```java
public interface ListInterface<T> {

 /**
  * Task: Adds a new entry to the end of the list. Entries currently in the
  * list are unaffected. The list's size is increased by 1.
  *
  * @param newEntry the object to be added as a new entry
  * @return true if the addition is successful, or false if the list is full
  */
 public boolean add(T newEntry);
```

Using Generic Type in a Java Class

```
package adt;

import java.io.Serializable;

public class ArrayList<T> implements ListInterface<T>, Serializable {

  private T[] array;
  private int numberOfEntries;
  private static final int DEFAULT_CAPACITY = 5;

  public ArrayList() {
    this(DEFAULT_CAPACITY);
  }
```

How a client creates a reference type variable when the class uses Generic Type T?

```java
public class TestArrayList{
    public static void main(String[] args) {

        ListInterface<Customer> custList = new ArrayList<>();

        custList.add(new Customer("123","Amy"));
        custList.add(new Customer("444","Dylan"));
```

Step 2: Implement the List ADT (2)

- **Step 2b: Write the Java class** (cont'd)
  - Implements the interface `ListInterface`
  - Operations are implemented as Java methods:
    - Core operations – as appears in the list ADT specification and also the interface `ListInterface`
    - Utility operations – to support the core operations. This are implemented as `private` methods.

Issues to consider for the operations

- **`add`** , **`remove`** , **`replace`** , **`getEntry`** work OK when valid position given

- **`remove`**, **`replace`** and **`getEntry`** not meaningful on empty lists

- A list could become full, what happens to **`add`**?

Method `add(newEntry)`

- Adds a new item *at the end* of the list
  - Assign new value at end
  - Increment **`length`** of list

0	1	2	3	4	5	6		length
apple	orange	durian	lemon	plum				5

`add(newPosition, newEntry)`

- Adds an item in at a specified position
  - Requires a utility method `makeRoom()` to shift elements ahead

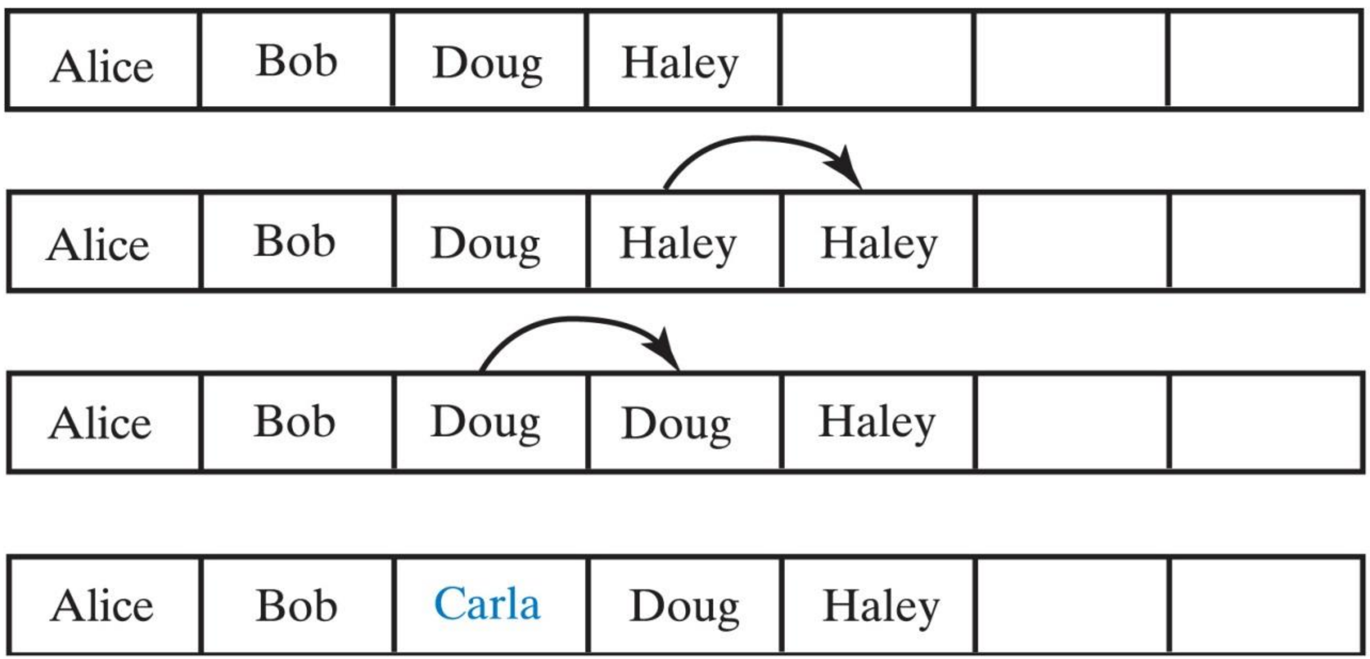
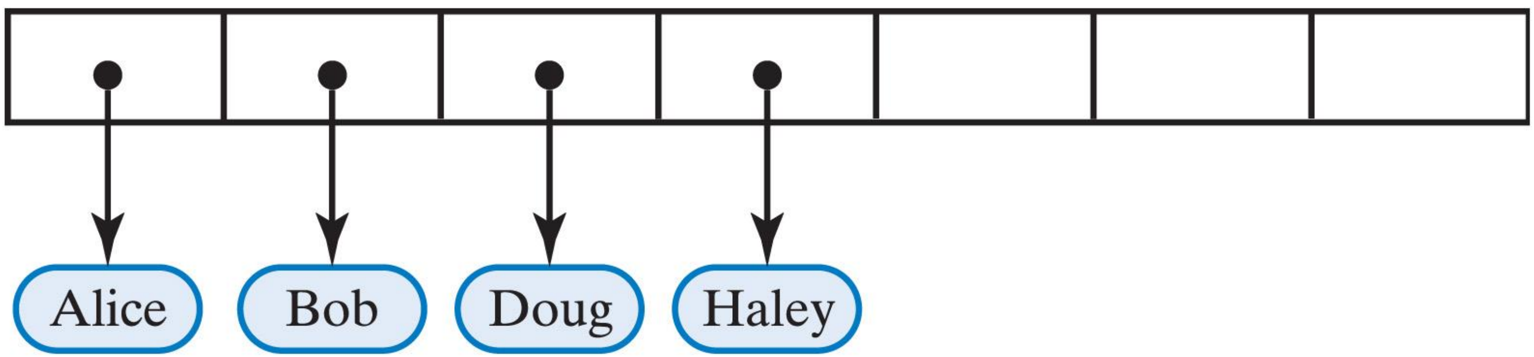


Fig. 5-3 Making room to insert Carla as third entry in an array.

Array of Objects References

- An array of objects actually contain references to those objects



- For simplicity, figures portray arrays as if they actually contained objects

Method `remove(givenPosition)`

- Removes the item at the specified position.
- Must shift existing entries to avoid gap in the array – requires the utility method `removeGap()`
  – Except when removing last entry
- Method must also handle error situations
  – When position specified in the remove is invalid
  – When `remove()` is called and the list is empty
  – Invalid call returns null value

Removing a List Entry

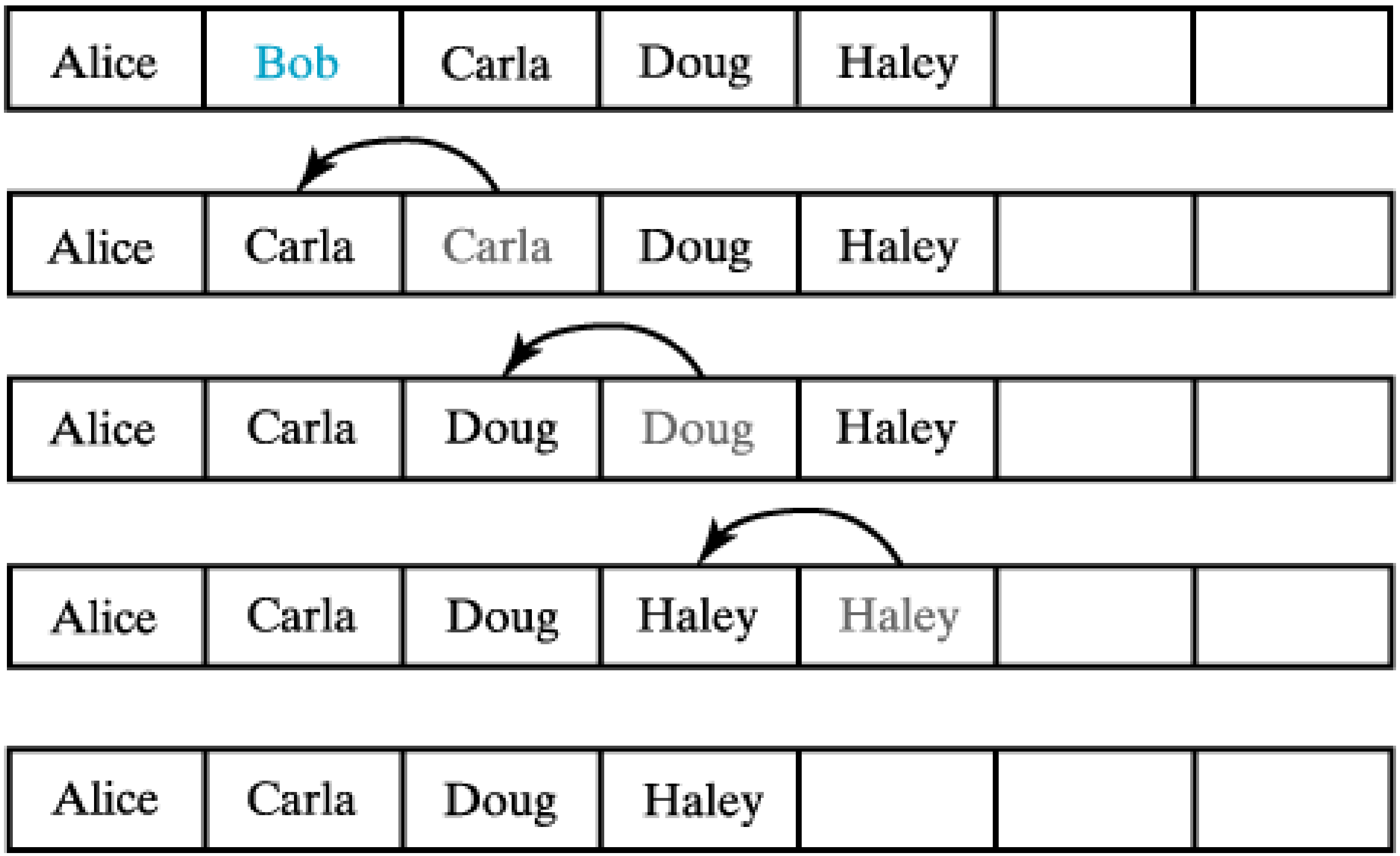


Fig. 5-5 Removing Bob by shifting array entries.

Algorithms for Other Methods?


```
public boolean replace(int givenPosition,
                       T newEntry);
public T getEntry(int givenPosition);
public boolean contains(T anEntry);
```

replace(int, T) Method

```java
@Override
public boolean replace(int givenPosition, T newEntry) {
  boolean isSuccessful = true;

  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries)) {
    array[givenPosition - 1] = newEntry;
  } else {
    isSuccessful = false;
  }

  return isSuccessful;
}
```

getEntry(int) method

```
@Override
public T getEntry(int givenPosition) {
  T result = null;

  if ((givenPosition >= 1) && (givenPosition <= numberOfEntries)) {
    result = array[givenPosition - 1];
  }

  return result;
}
```

contains(T) method

```
@Override
public boolean contains(T anEntry) {
  boolean found = false;
  for (int index = 0; !found && (index < numberOfEntries); index++) {
    if (anEntry.equals(array[index])) {
      found = true;
    }
  }
  return found;
}
```

The Java Implementation

Refer to:

`Chapter4\adt\`**`ArrayList.java`**

Note:

- In the interface **`ListInterface`**, each abstract method corresponds to an ADT list operation.
- Since the **`ArrayList`** class implements **`ListInterface`**, **`ArrayList`** contains the implementation of each abstract method of **`ListInterface`**.

Problem

- What if the array becomes full, i.e. all the array locations are assigned entries?

Expanding an Array (1/4)

- An array has a fixed size
  - If we need a larger list, we are in trouble
- When array becomes full, move its contents to a larger array (dynamic expansion)
  - Copy data from original to new location
  - Manipulate names so new location keeps name of original array
- Need two utility methods for expanding an array:
  - **`isArrayFull()`** to determine if the array is already full
  - **`doubleArray()`** to expand the array

Expanding an Array (2/4)

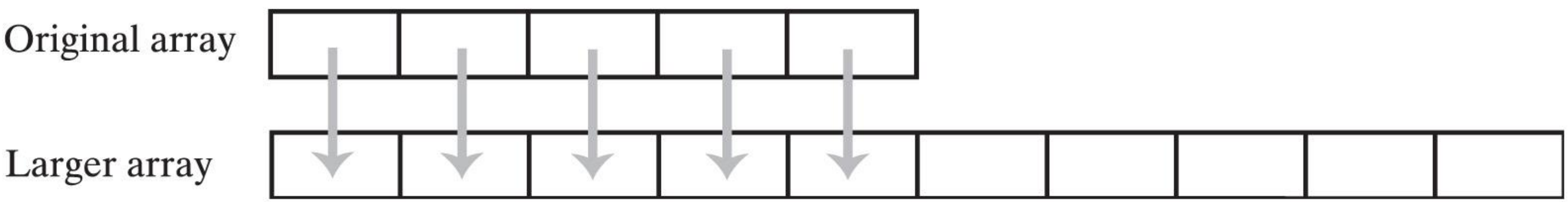


Fig. 5-6 The dynamic expansion of an array copies the array's contents to a larger second array.

Expanding an Array (3/4)

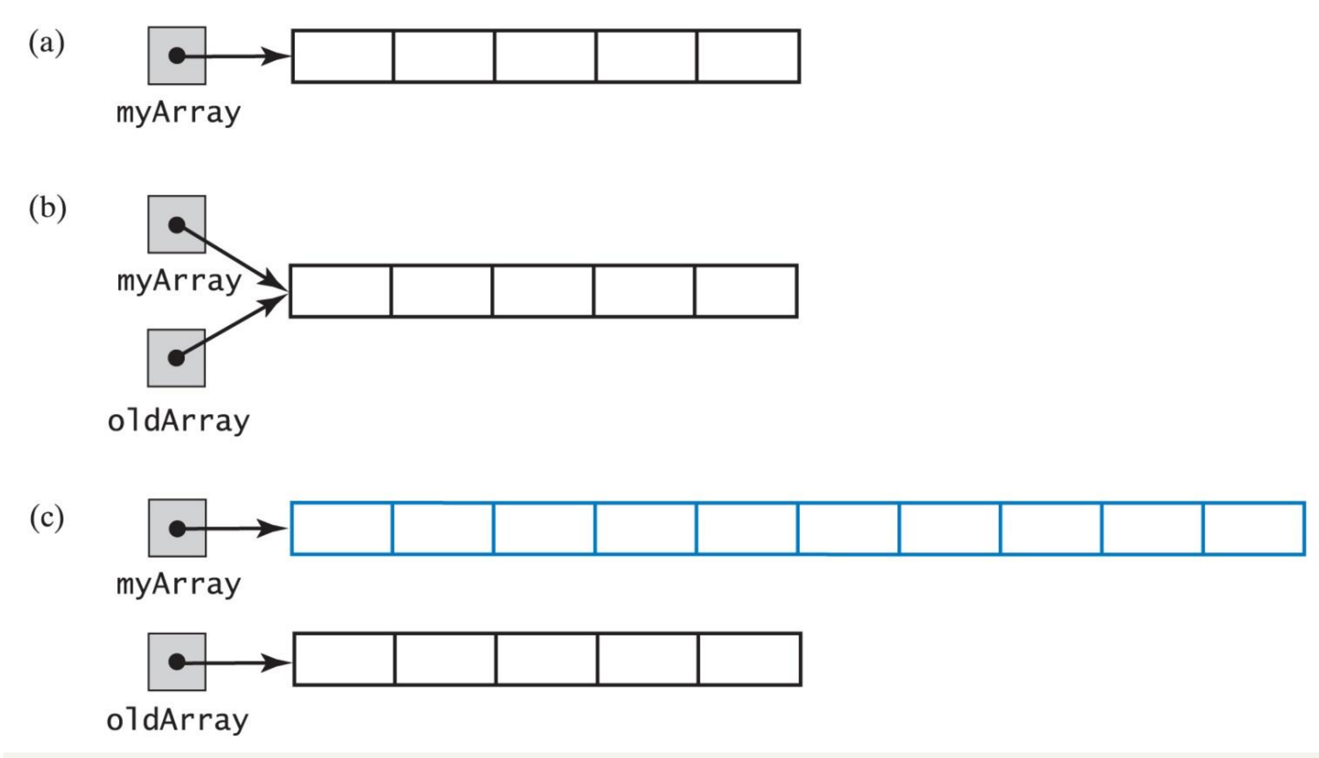


Fig. 5-7 (a) an array;
(b) the same array with two references;
(c) the two arrays, reference to original array now referencing a new, larger array

Expanding an Array (4/4)

- Code to accomplish the expansion shown in Fig. 5-7, previous slide

```
int [] myArray = new int [INITIAL_SIZE];
int [] oldArray = myArray;
     // save reference to myArray
myArray = new int [2 * oldArray.length];
     // double size of array
for (int index = 0 ;
         index < oldArray.length ;
         index++)
       myArray [index] = oldArray [index];
```

Expandable List Implementation

- Change the **`isFull`** to always return false
  - We will expand the array when it becomes full
  - We keep this function so that the original interface does not change
- The **`add()`** methods will double the size of the array when it becomes full
- Now declare a **private** method **`isArrayFull`**
  - Called by the **`add()`** methods

Pros and Cons of Array Implementation for the ADT List

☑ Retrieving an entry is fast

☑ Adding an entry at the end of the list is fast

✘ Adding or removing an entry that is between other entries requires shifting elements in the array

✘ Increasing the size of the array requires copying elements

Sample Code

- Chapter4\adt\
  - **ListInterface.java**
  - **ArrayList.java**
- Chapter4\entity\
  - **Runner.java**
- Chapter4\client\
  - **Registration.java**

Stacks

Stacks

- New items are added to the top of the stack, i.e. the item most recently added is always on the top. The most recently added item is always the next item to be removed.
- Exhibits LIFO behavior.

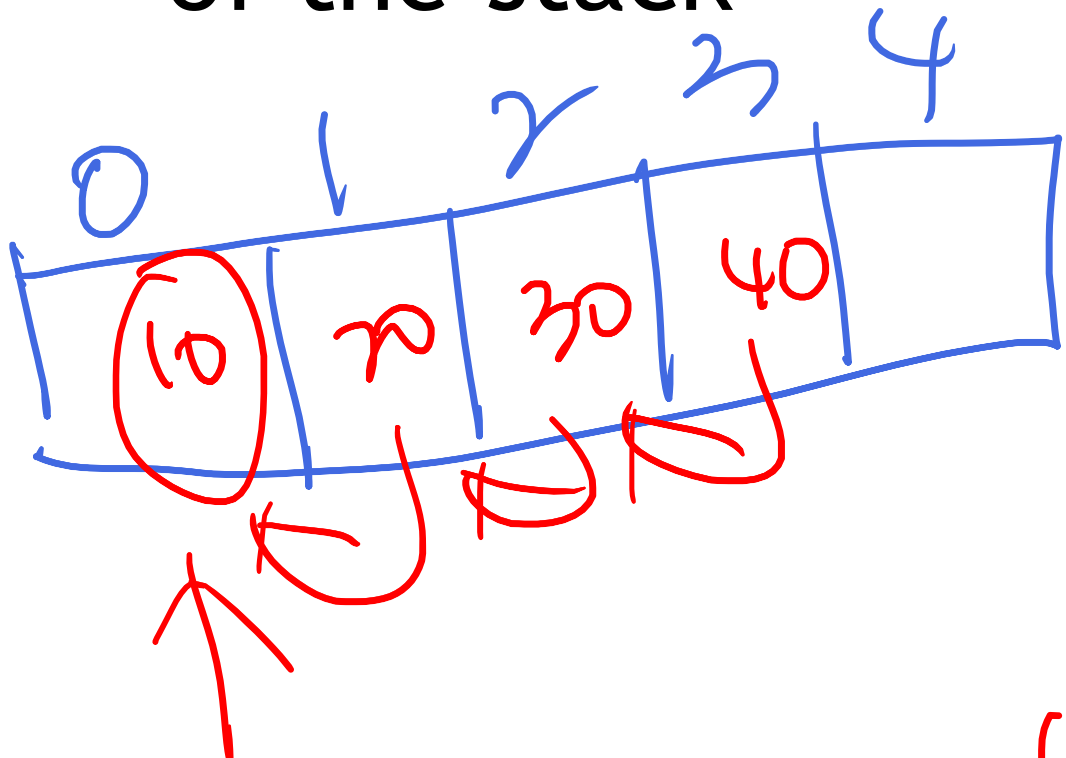
ADT Stack's Basic Operations

- **push(newEntry)**
- **pop()**
- **peek()**
- **isEmpty()**
- **clear()**

Array Stack Implementation: Consideration

- When using an array to implement a stack
  - *The array's first element should represent the bottom of the stack*
  - *The last occupied location in the array represents the stack's top*
- This avoids shifting of elements of the array if it were done the other way around

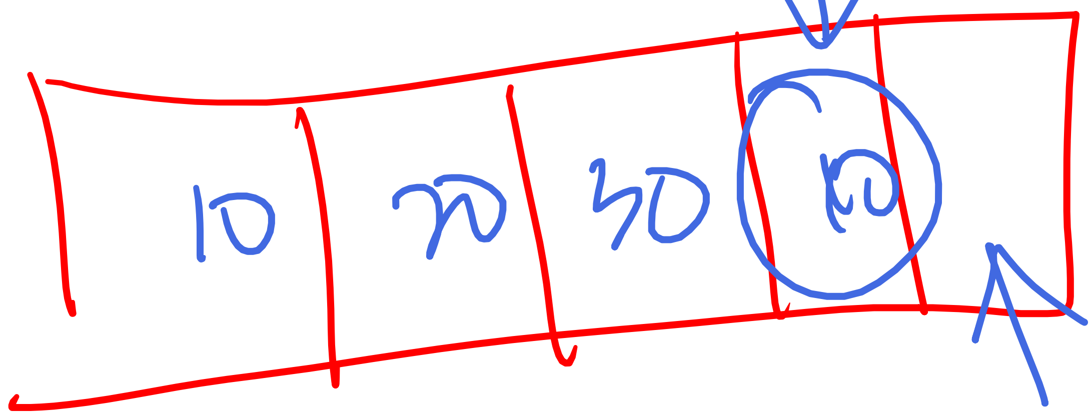
Using the **first** element as the top of the stack



s.pop()

Using the last element as the top of the stack

s.pop()



s.push(50)

Comparison of 2 approaches

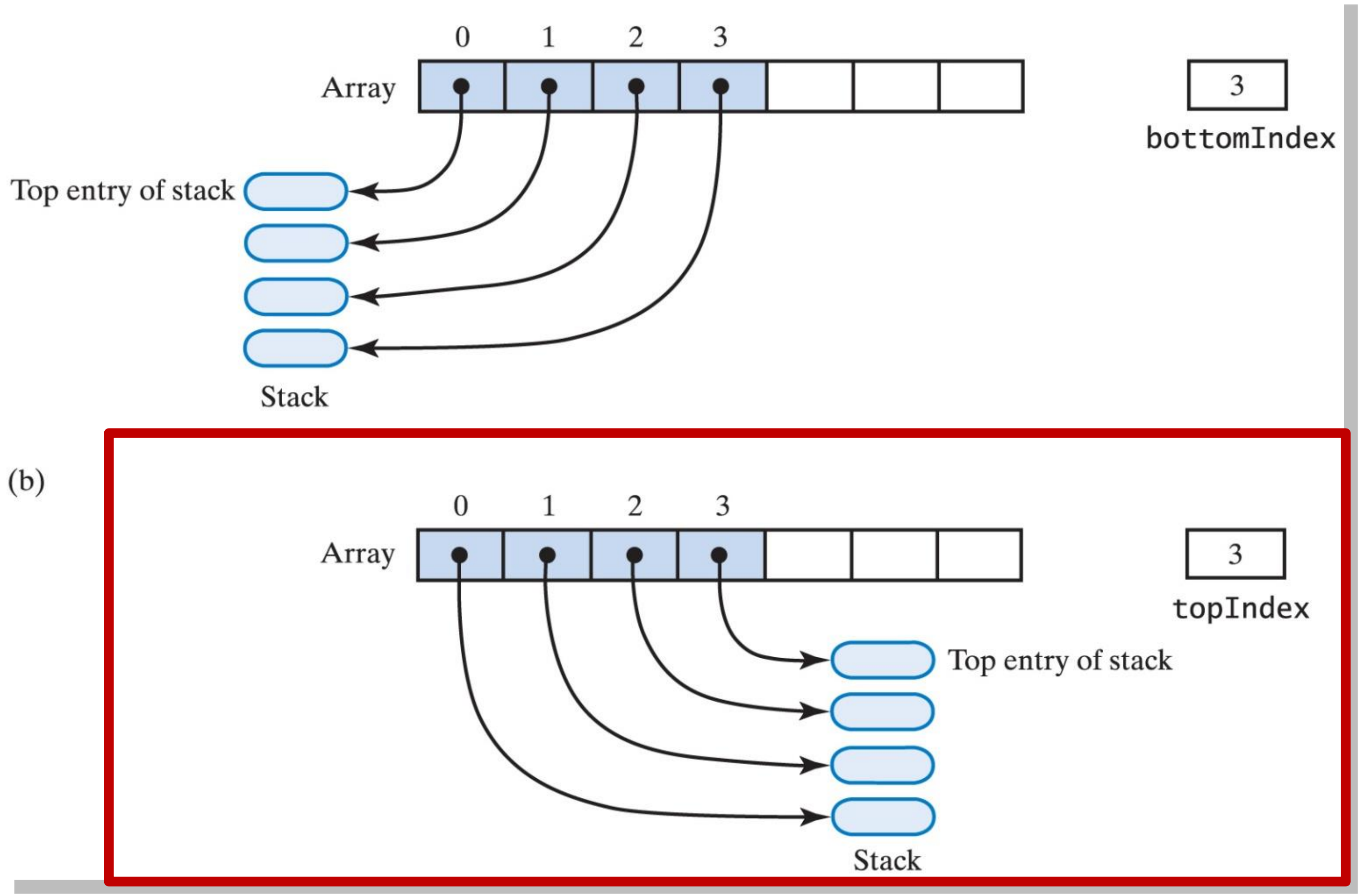


Fig. 22-4 An array that implements a stack; its first location references (a) the top of the stack; (b) the bottom of the stack

Array Stack Implementation

- Java interface: refer to **`StackInterface.java`**
- Data fields in the Java class:
  - An array – to store the entries of the stack
  - An integer variable – represents the array index of the top entry; initialized to -1 to indicate an empty stack

```
T[] array;        // array of stack entries
int topIndex;     // index of the top entry
```

  - Java class: refer to **`ArrayStack.java`**

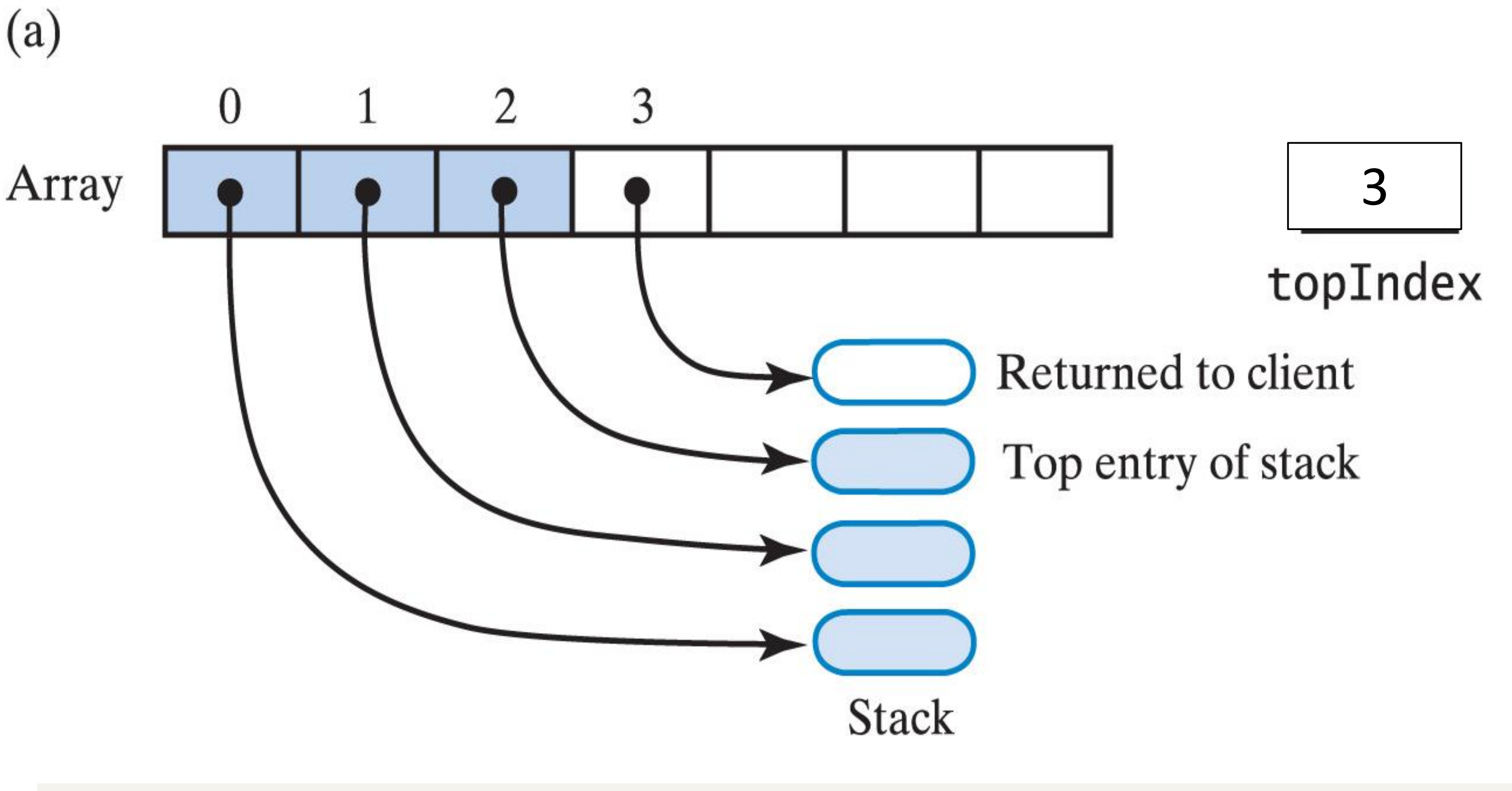
Method `push(newEntry)`

- Adds a new item *at the top* of the stack
  1. Increment **`topIndex`**
  2. Assign new value at the array location indicated by **`topIndex`**

Method `pop()` (1)

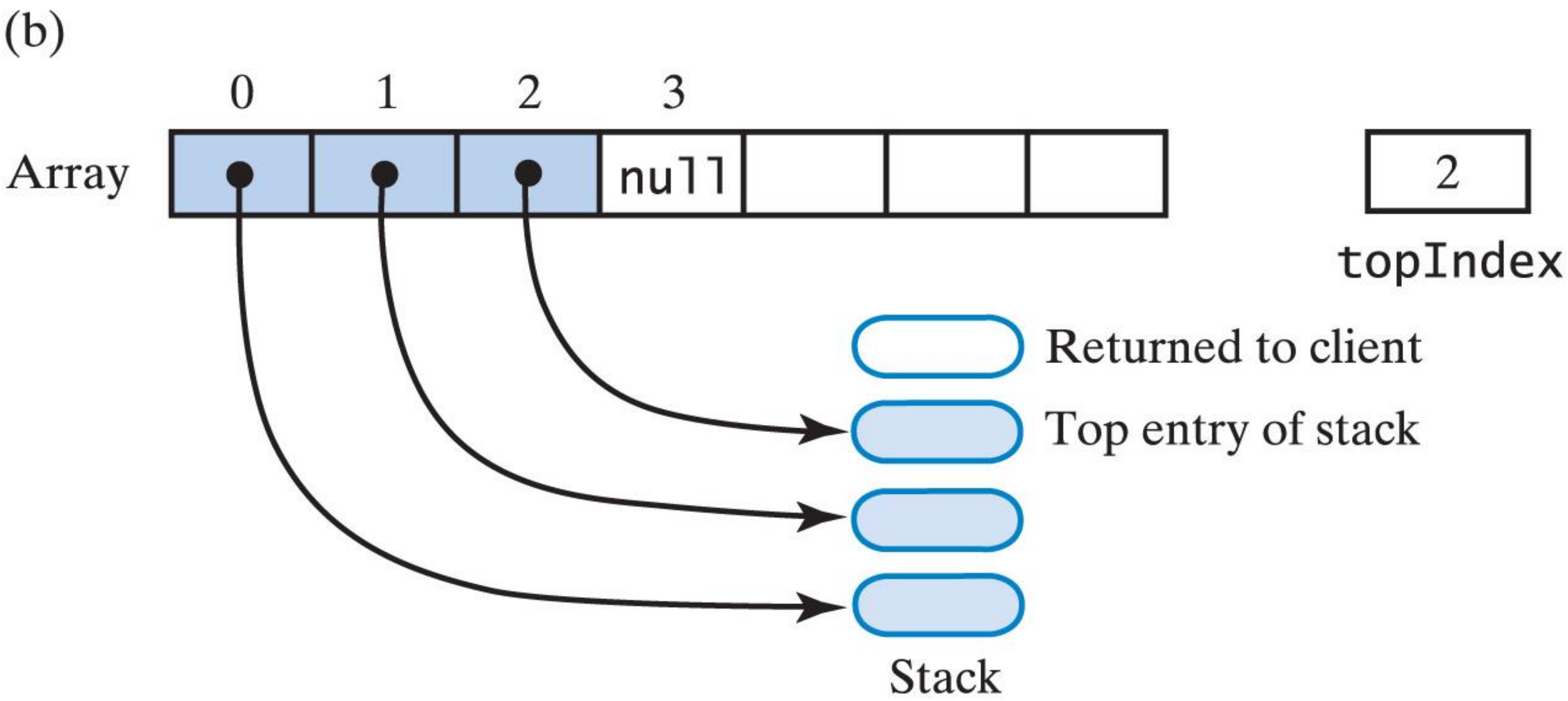
- Removes the entry *at the top* of the stack
  1. Assign the entry at the array location indicated by **`topIndex`** to a temporary variable (to be returned)
  2. Decrement **`topIndex`**

Method **pop()** (2)



Assign the value at the array location indicated by **`topIndex`** to a temporary variable to be returned to the calling method

Method pop() (3)



Setting **array[topIndex]=null** and then decrement **topIndex**

Exercise 4.1

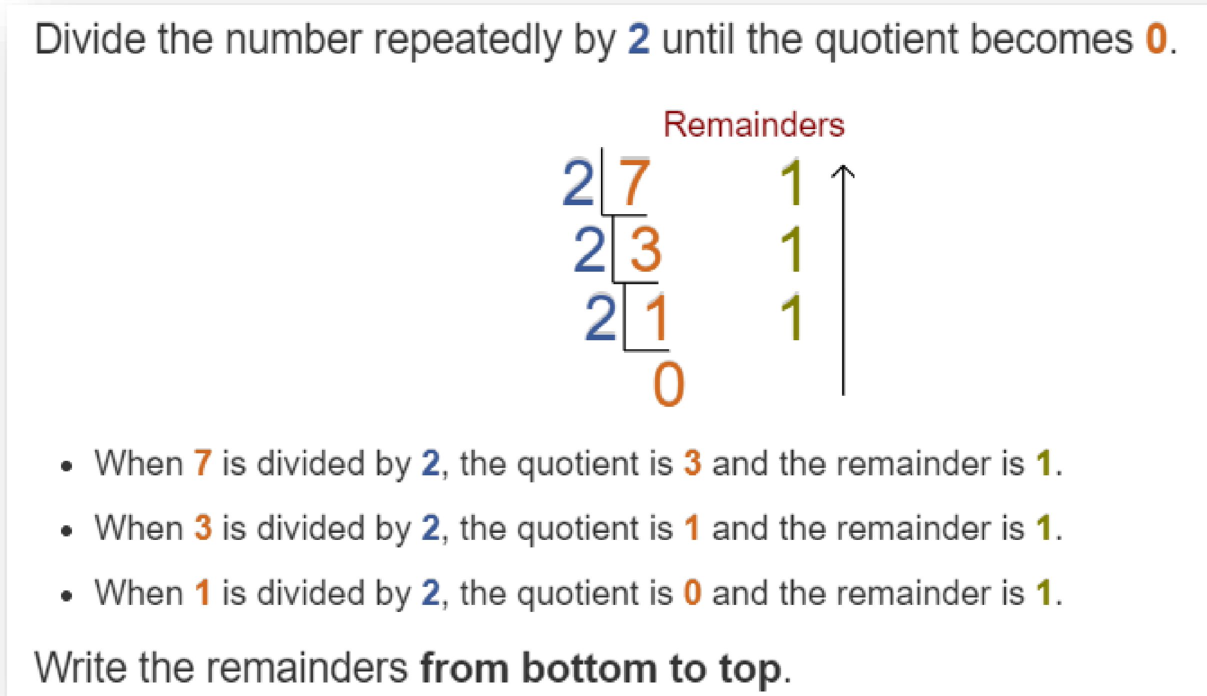
Write the algorithm for the method **`convertNumberToBinary(int number)`** to convert the given number to its equivalent binary (base-2) representation and returns the result as a string value.

Hint: use a stack.

```
1. Create a stack of Integers
2. while number is not 0
   2.1 remainder = number % 2
   2.2 push remainder on the stack
   2.3 update number i.e., number /= 2
3. Declare variable binaryStr as an empty string
4. while the stack is not empty
   4.1 pop the top value from the stack
   4.2 concatenate the top value to binaryStr
5. return binaryStr
```

Exercise 4.1: Example 7

- 7 % 2 = 1
- 3 % 2 = 1
- 1 % 2 = 1

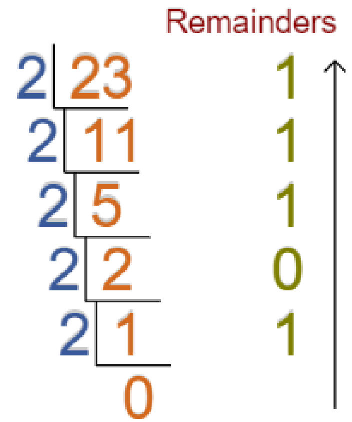


- The decimal number 7 is **111** in binary form

Exercise 4.1: Example 23

- 23 % 2 = 1
- 11%2 = 1
- 5%2 = 1
- 2%2 = 0
- 1%2 = 1

Divide the number repeatedly by **2** until the quotient becomes **0**.



- When **23** is divided by **2**, the quotient is **11** and the remainder is **1**.
- When **11** is divided by **2**, the quotient is **5** and the remainder is **1**.
- When **5** is divided by **2**, the quotient is **2** and the remainder is **1**.
- When **2** is divided by **2**, the quotient is **1** and the remainder is **0**.
- When **1** is divided by **2**, the quotient is **0** and the remainder is **1**.

Write the remainders **from bottom to top**.

- The decimal number **23** is **10111** in Binary Form.

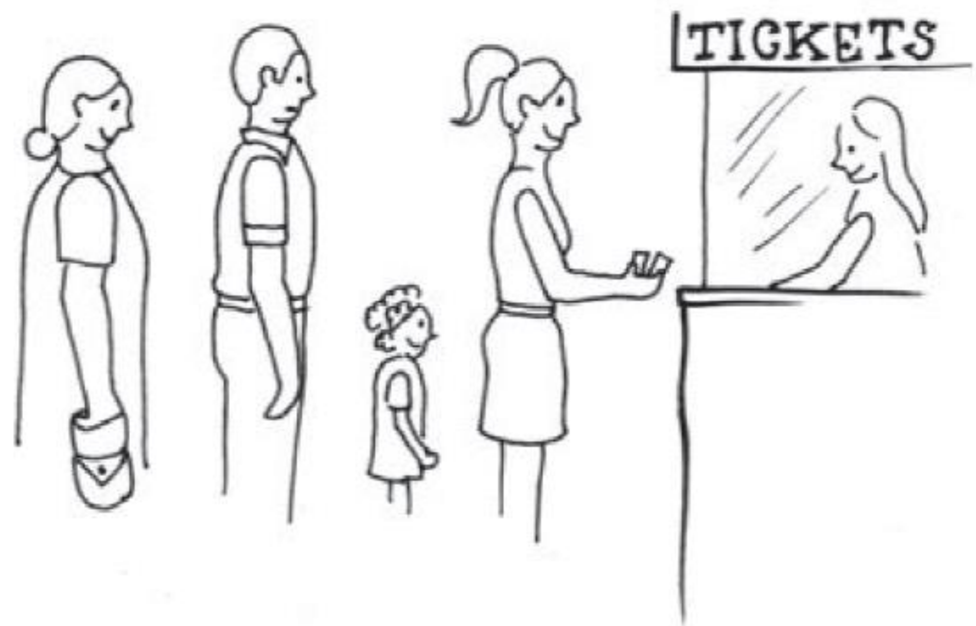
Decimal to Binary Conversion

- Answers with step-by-step
- https://madformath.com/calculators/basic-math/base-converters/decimal-to-binary-converter-with-steps/decimal-to-binary-converter-with-steps

Sample Code

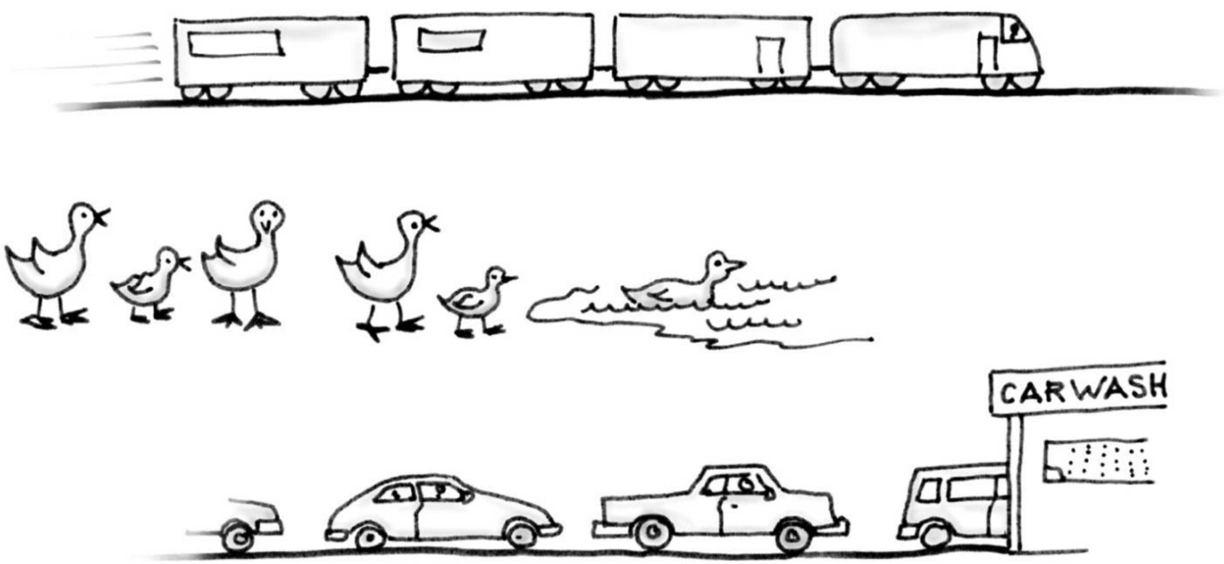
- `Chapter4\adt\`
  - **`StackInterface.java`**
  - **`ArrayStack.java`**
- `Chapter4\client\`
  - **`StringReversal.java`**

Queues



Queues

- Queue organizes entries according to order of entry - exhibits FIFO behavior
- All additions are at the back of the queue. Front of queue has items added first



ADT Queue’s Basic Operations

- **`enqueue`**
- **`dequeue`**
- **`getFront`**
- **`isEmpty`**
- **`clear`**

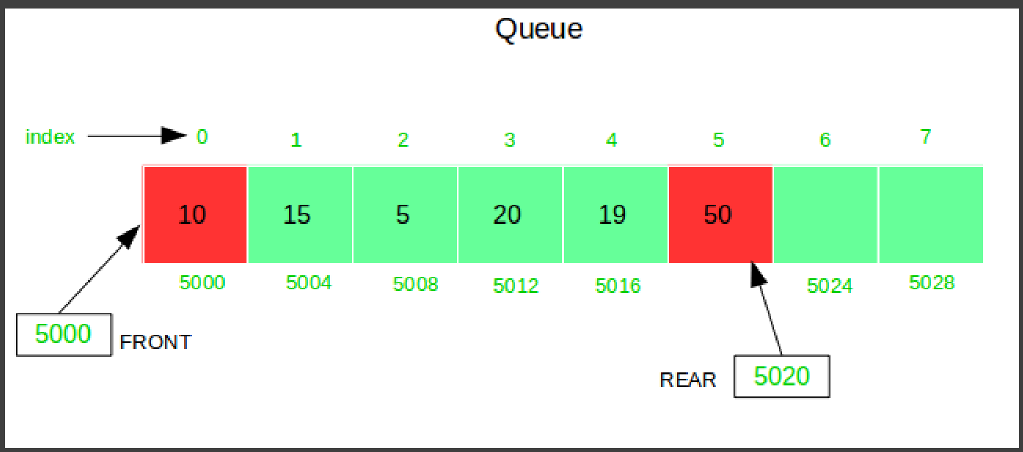
Array Queue Implementation

- Java interface: refer to `QueueInterface.java`
- Data fields in the Java class:
  - An array – to store the entries of the queue
  - Two integer variables – to represent
    - the array index of the **front** of the queue and
    - the array index of the **back** of the queue

```
T[] array;          // array of queue entries
int frontIndex;     // index of the front entry
int backIndex;      // index of the back entry
```

Array Queue Implementation: Variations

1. Linear array with fixed front
2. Linear array with dynamic front
3. Circular array



Method 1: Linear Array with Fixed Front

Data Fields

Method 1:
Linear Array
Fixed Front

- The front of the queue is *fixed* to **`array[0]`**, i.e., **`frontIndex`** is *always* `0`.
- **`backIndex`** initialized to `-1` to indicate an empty queue

Method **enqueue()**

Method 1:
Linear Array
Fixed Front

1. Increment **backIndex**
2. Assign new value at the array location indicated by **backIndex**

```
public void enqueue(T newEntry) {
  if (!isArrayFull()) {
    backIndex++;
    array[backIndex] = newEntry;
  }
}
```

Method 1:
Linear Array
Fixed Front

Method **dequeue()**

1. Assign the entry at array location **0** to a temporary variable (to be returned)
2. Shift entries from array location **1** to **backIndex** one step towards the front of the array
3. Decrement **backIndex**

Method 1:
Linear Array
Fixed Front

Method dequeue()

```
public T dequeue() {
  T front = null;
  if (!isEmpty()) {
    front = array[frontIndex];      // shift remaining array items forward one position
    for (int i = frontIndex; i < backIndex; ++i) {
      array[i] = array[i + 1];
    }
    backIndex--;
  }
  return front;
}
```

Method isEmpty()

Method 1:
Linear Array
Fixed Front

- The queue is empty if **backIndex** is equal to **-1**

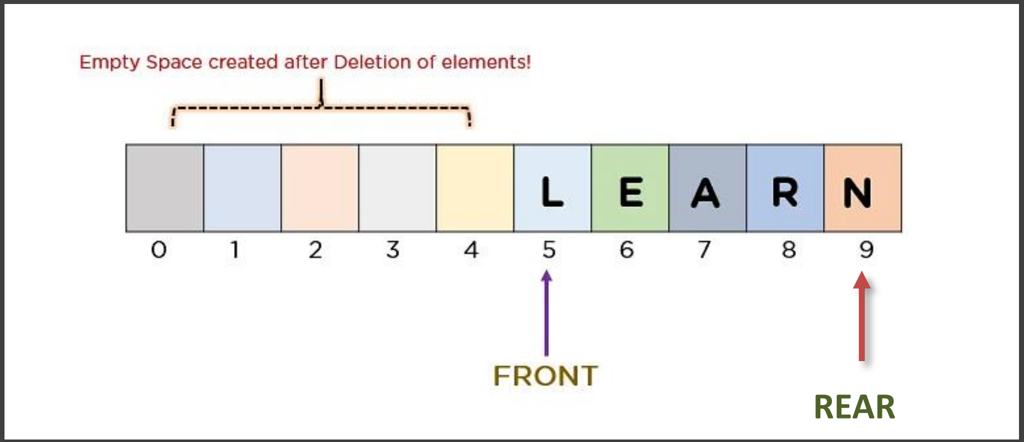
```
public boolean isEmpty() {
  return frontIndex > backIndex;
}
```

Method 1:
Linear Array
Fixed Front

Strength and Weakness

- ☑ Easy to understand as it is similar to how everyone else in a queue moves forward a step
- ✘ The **dequeue** operation is inefficient: there's overhead incurred as must shift entries each time we remove an entry

Method 2: Linear Array with Dynamic Front



Method 2:
Linear Array
Dynamic Front

Data Fields

- `frontIndex` is *dynamic*, *i.e.*, we instead "move" (i.e. update) `frontIndex`
- `backIndex` initialized to `-1`; `frontIndex` initialized to `0`

Method **enqueue()**

Method 2:
Linear Array
Dynamic Front

1. Increment **backIndex**
2. Assign new value at the array location indicated by **backIndex**

Method **dequeue()**

Method 2:
Linear Array
Dynamic Front

1. Assign the entry at array location **frontIndex** to a temporary variable (to be returned)
2. Increment **frontIndex**

Method 2: Linear Array Dynamic Front

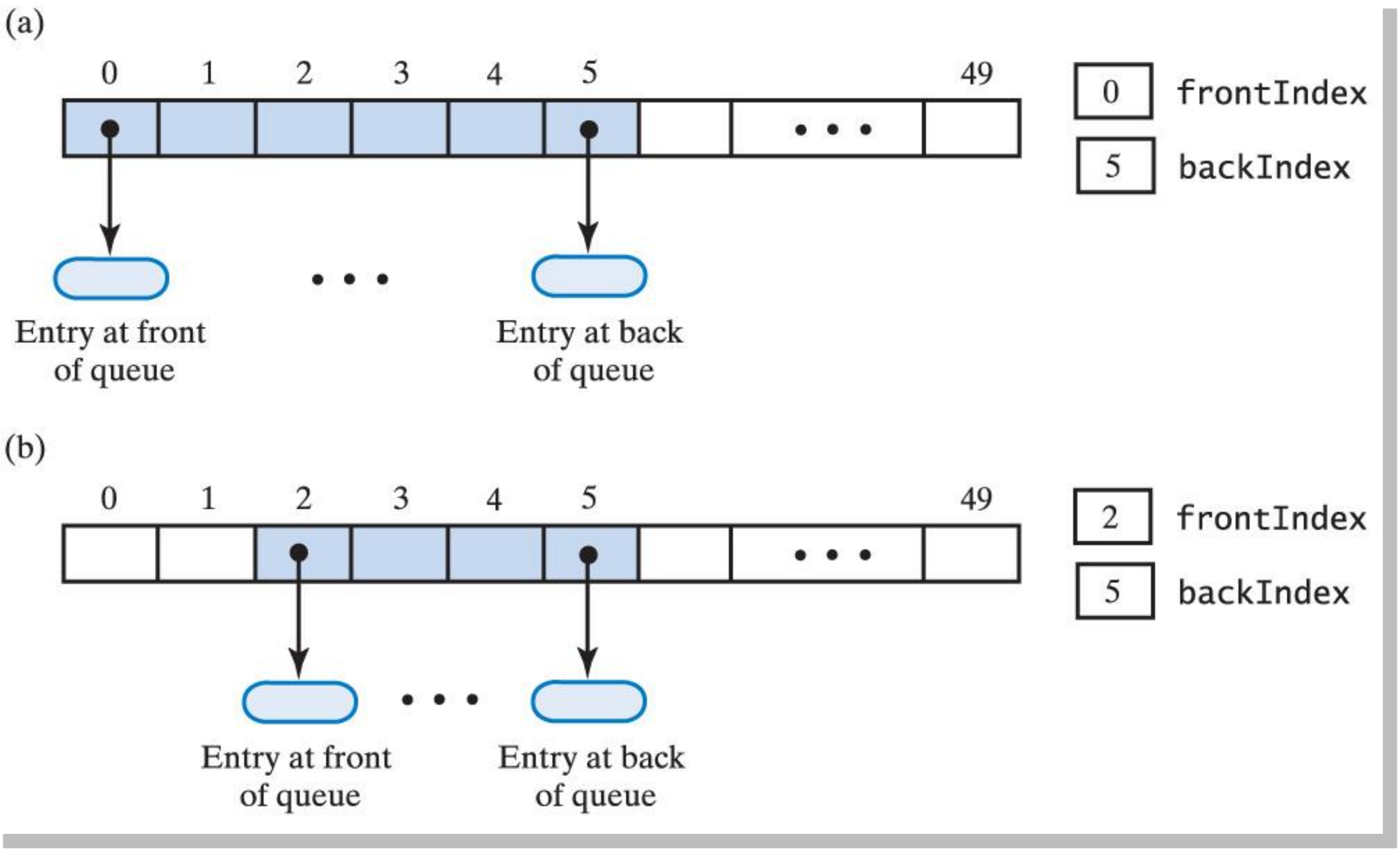


Fig. 24-6 An array that represents a queue without shifting its entries: (a) initially; (b) after removing the front twice;

Method `isEmpty()`

Method 2:
Linear Array
Dynamic Front

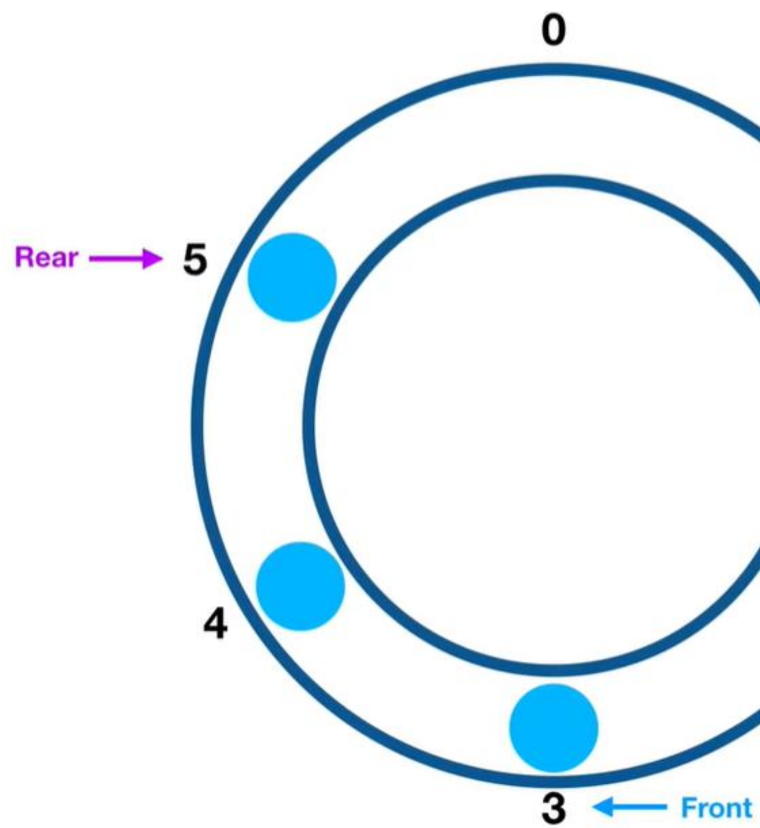
- The queue is empty if `backIndex < frontIndex`

Strength and Weakness

Method 2:
Linear Array
Dynamic Front

- ☑ Do not have to shift entries after each `dequeue` operation.
- ✘ Problem: *Rightward drift*, i.e. the array can become "full" when the last array location has been occupied but there are empty locations in the beginning part of the array.
  - How to use the empty locations?

Method 3: Circular Array



Data Fields

Method 3: Circular Array

- When queue reaches end of array, add subsequent entries to beginning
- Array behaves as though it were circular
  - First location follows last one
- **`backIndex`** initialized to `-1`; **`frontIndex`** initialized to `0`
- Use *modulo arithmetic* to update indices:

```
backIndex = (backIndex + 1) % array.length
frontIndex = (frontIndex + 1) % array.length
```

Method 3: Circular Array

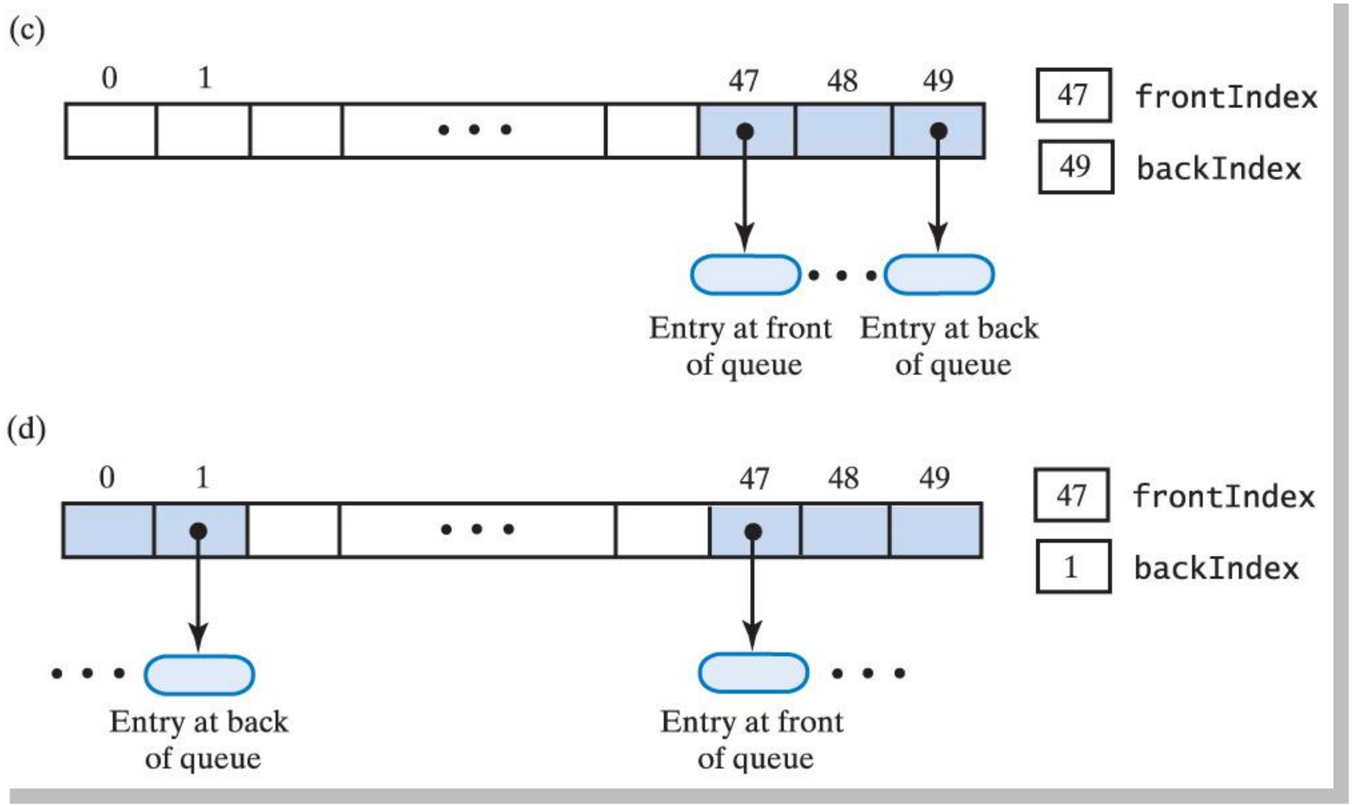


Fig. 24-6 An array that represents a queue without shifting its entries: (c) after several more additions & removals; (d) after two additions that wrap around to the beginning of the array

Method 3: Circular Array

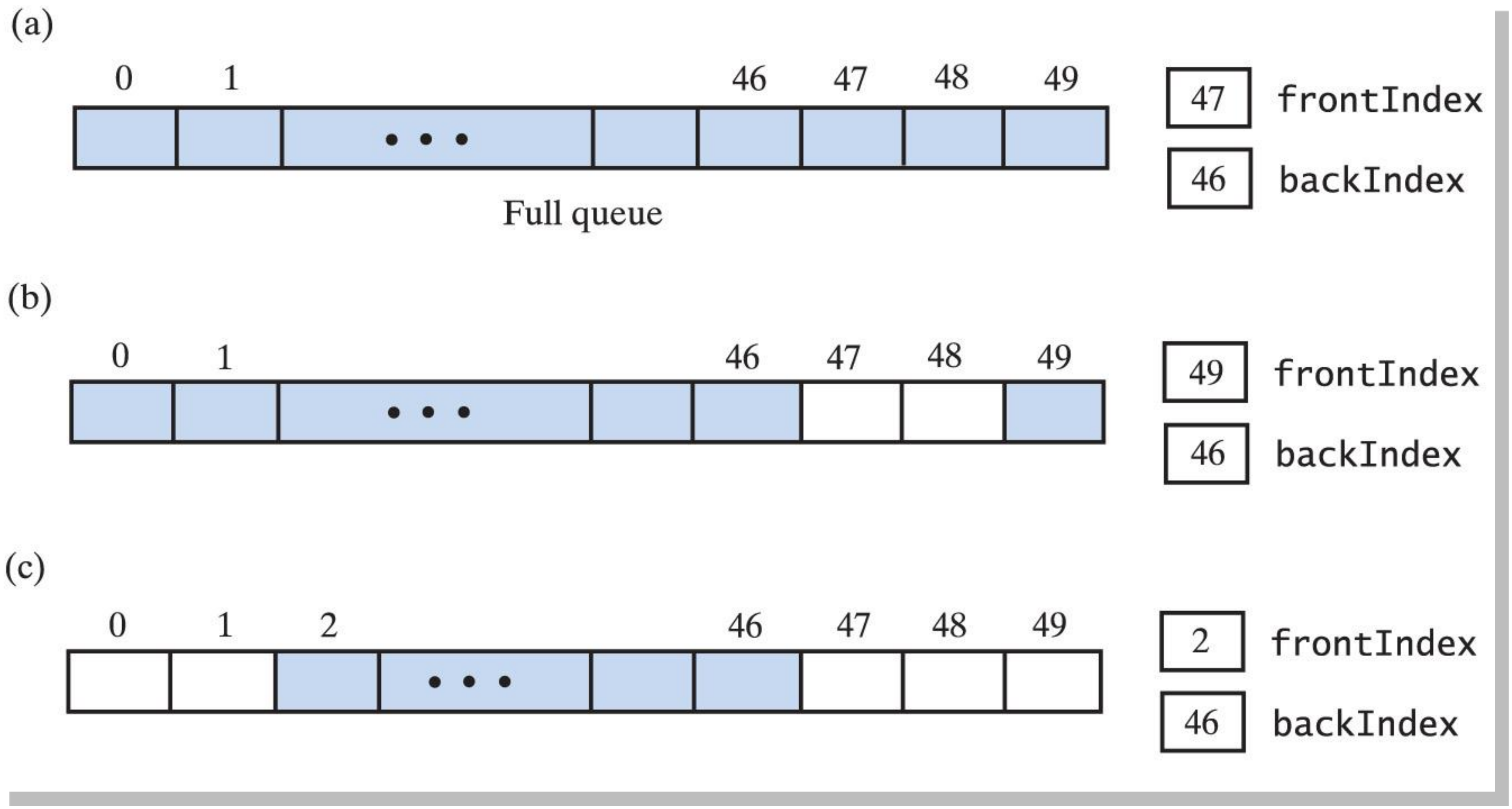


Fig. 24-7 A circular array that represents a queue: (a) when full; (b) after removing 2 entries; (c) after removing 3 more entries;

Method 3: Circular Array

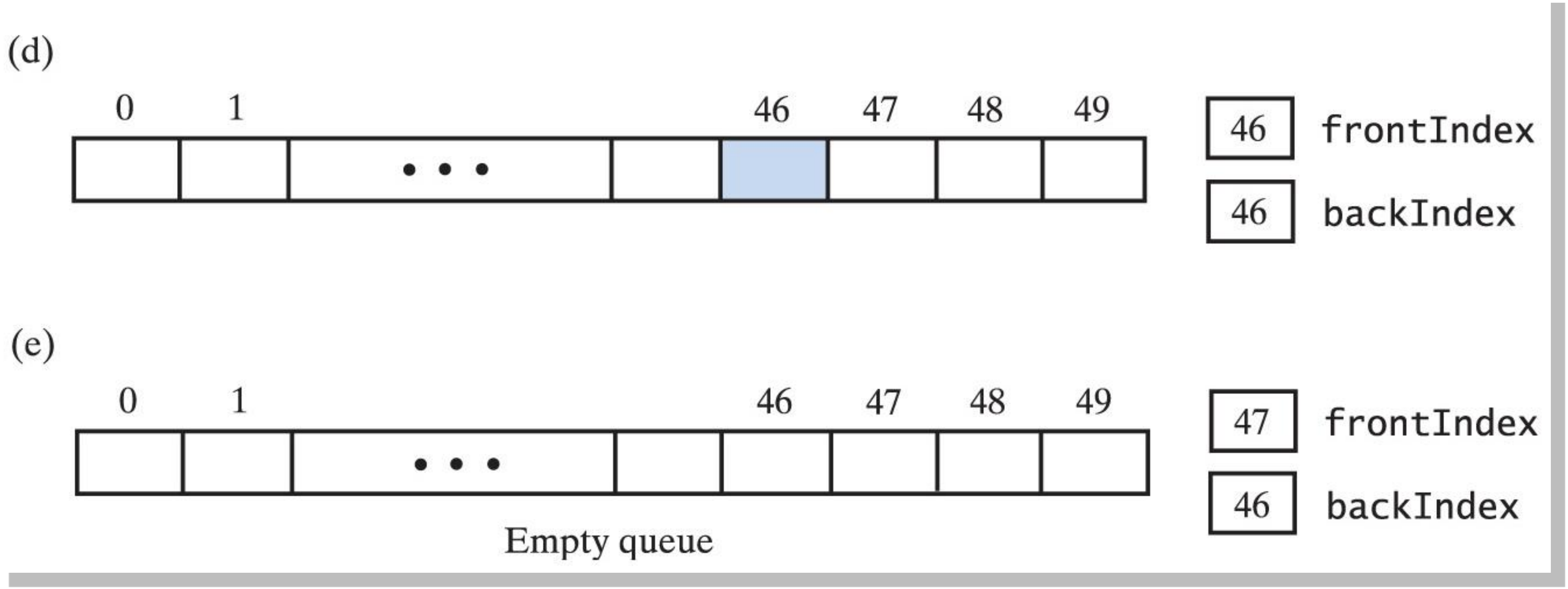


Fig. 24-7 A circular array that represents a queue:
(d) after removing all but one entry;
(e) after removing remaining entry.

Method 3: Circular Array

Method enqueue()

1. Update **backIndex** using modulo arithmetic:

   backIndex = (backIndex + 1) % array.length

2. Assign new value at the array location indicated by **backIndex**

```
public void enqueue(T newEntry) {
  if (!isArrayFull()) {
    backIndex = (backIndex + 1) % array.length;
    array[backIndex] = newEntry;
  }
}
```

Method **dequeue()**

Method 3: Circular Array

1. Assign the entry at array location **`frontIndex`** to a temporary variable (to be returned)
2. Update **`frontIndex`** using modulo arithmetic:

   `frontIndex = (frontIndex+1) % array.length`

```
public T dequeue() {
  T front = null;

  if (!isEmpty()) {
    front = array[frontIndex];
    array[frontIndex] = null;
    frontIndex = (frontIndex + 1) % array.length;
  }

  return front;
}
```

Circular Array Implementation of a Queue

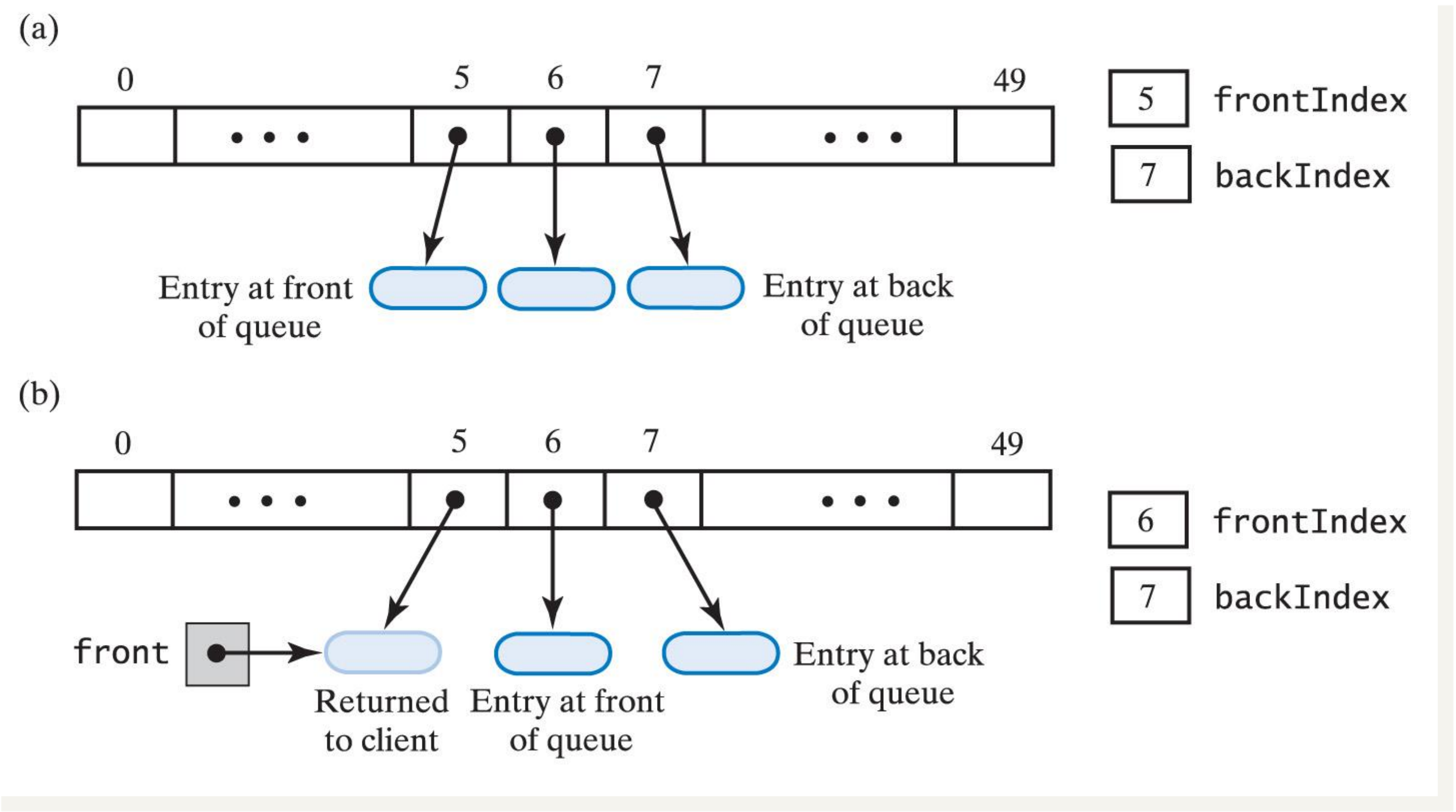


Fig. 24-9 An array-base queue: (a) initially; (b) after removing its front by incrementing **`frontIndex`**;

Circular Array Implementation of a Queue

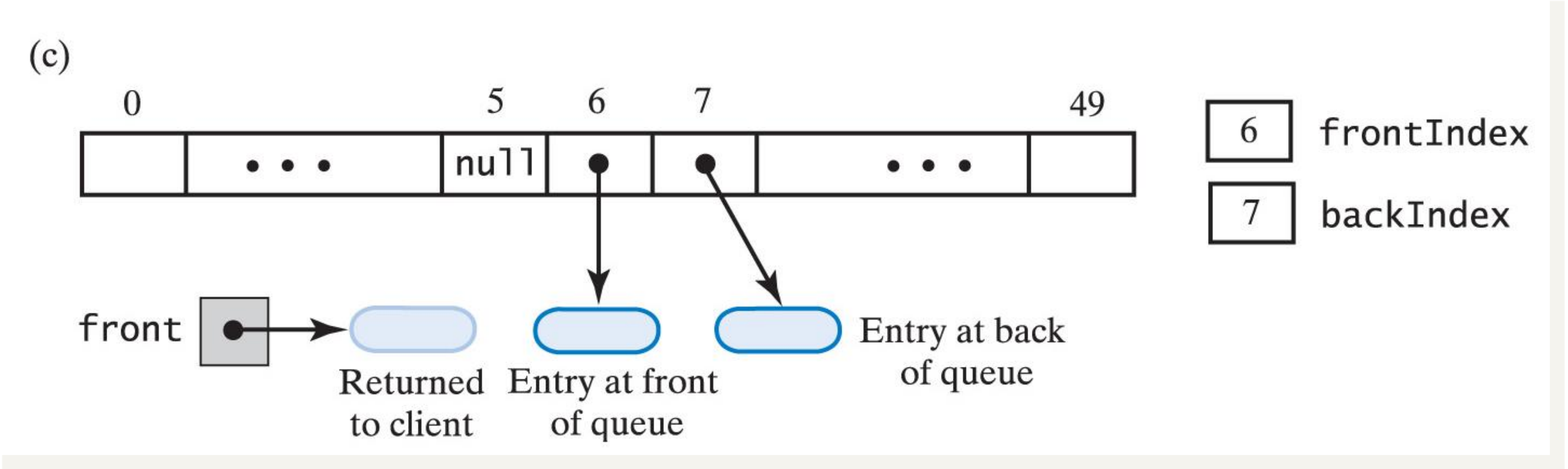


Fig. 24-9 An array-base queue: (c) after removing its front by setting **`queue[frontIndex]`** to **`null`**, then incrementing **`frontIndex`**.

Method 3: Circular Array

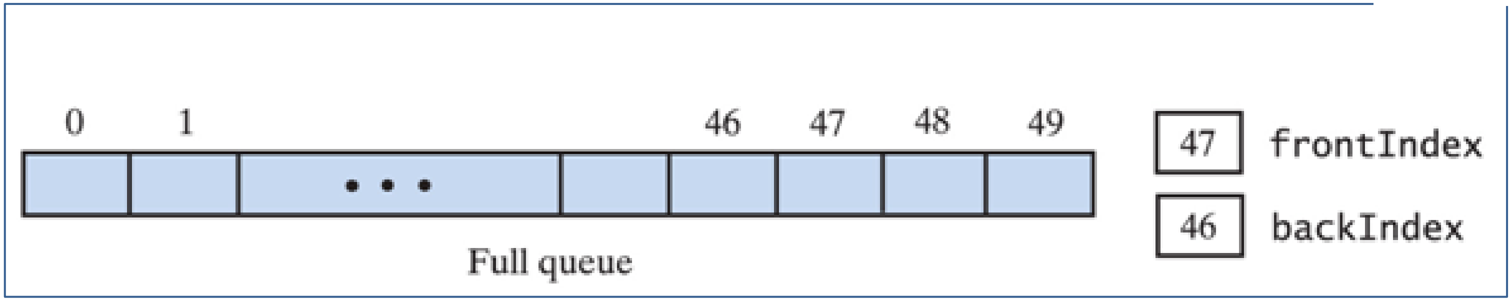
Strength and Weakness

- ☑ No rightward drift problem
  - No wasted array locations
  - Do not have to shift entries after the last array location is used
- ✘ Problem: *How to detect when the queue is empty and when the array is already full?*
  - Note: with circular array

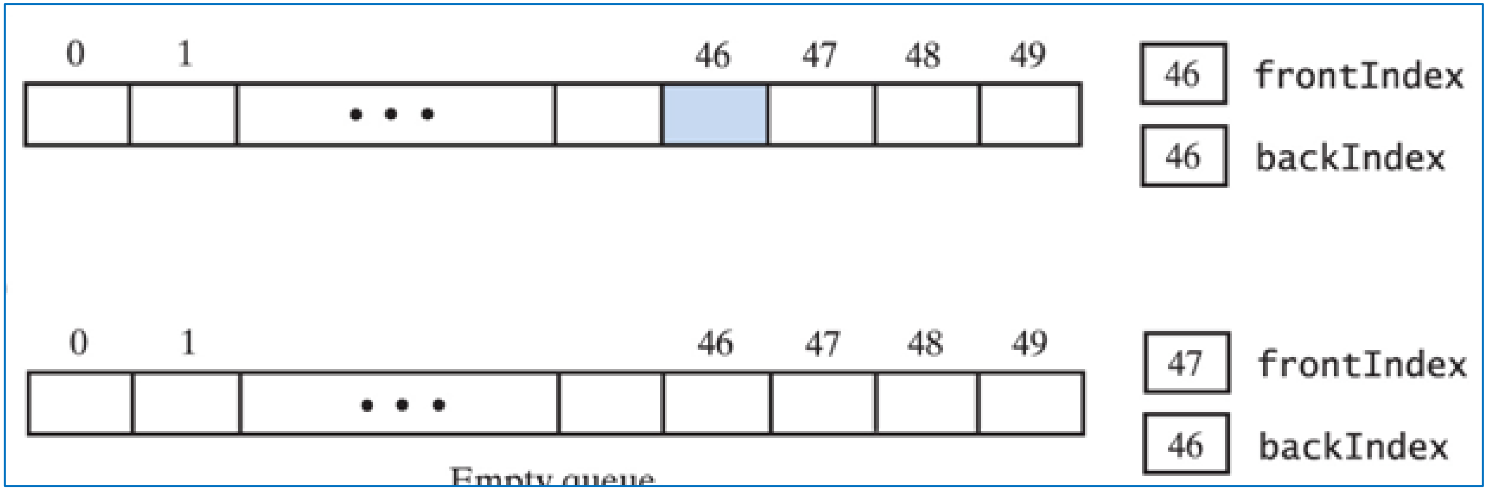
    `frontIndex == backIndex + 1`

    both when queue is empty and when full

Method 3: Circular Array



Observe that the relative positions of `frontIndex` and `backIndex` are the same for full queue (figure above) and empty queue (figure below) .



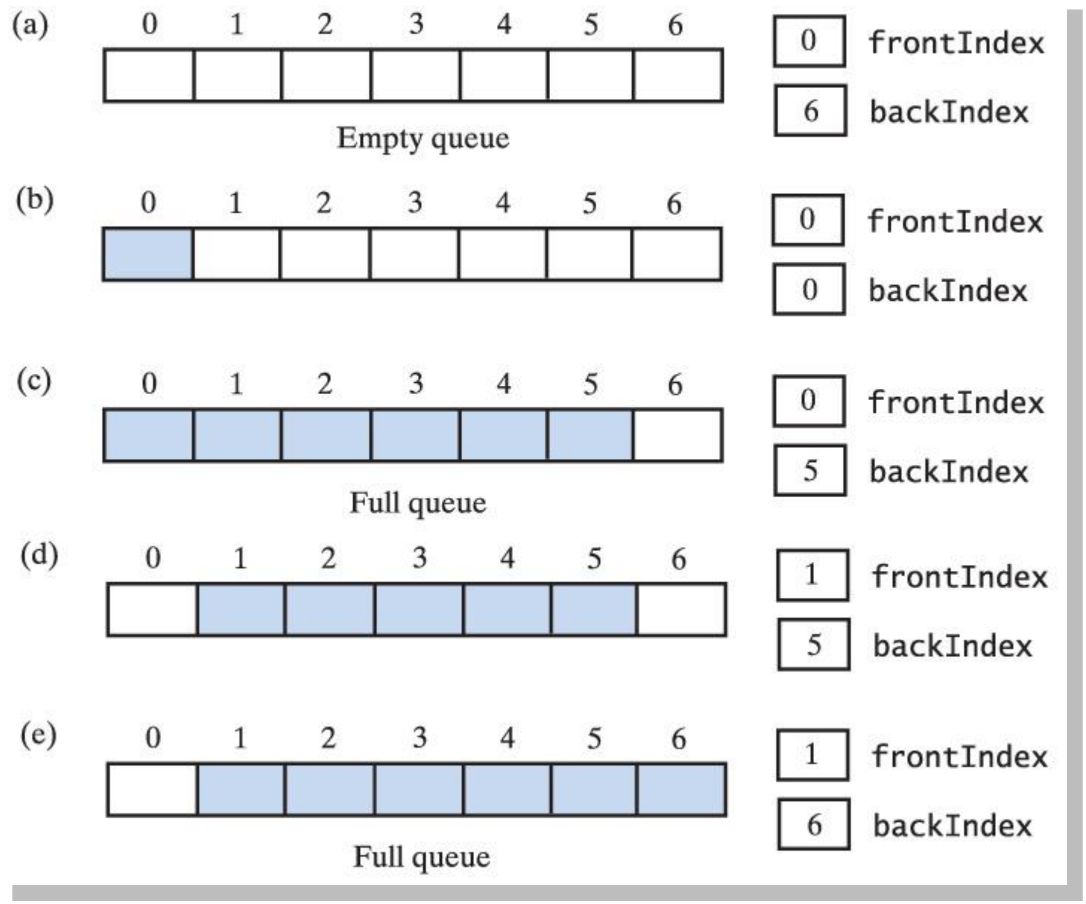
Method 3:
Circular Array

Solutions to Detect Empty and Full Queues

1. Use a counter to keep track of the total entries in the queue
   - **Empty queue** detected when **counter is 0**
   - **Full queue** detected when **counter equals array length**
2. Leave one unused (vacant) location in the array
   - **Empty queue** detected when **`frontIndex`** is one location “in front” of **`backIndex`** (remember the wraparound action)
   - **Full queue** detected when only one vacant array location left.

A Circular Array with One Unused Location

Fig. 24-8 A seven-location circular array that contains at most six entries of a queue … continued →



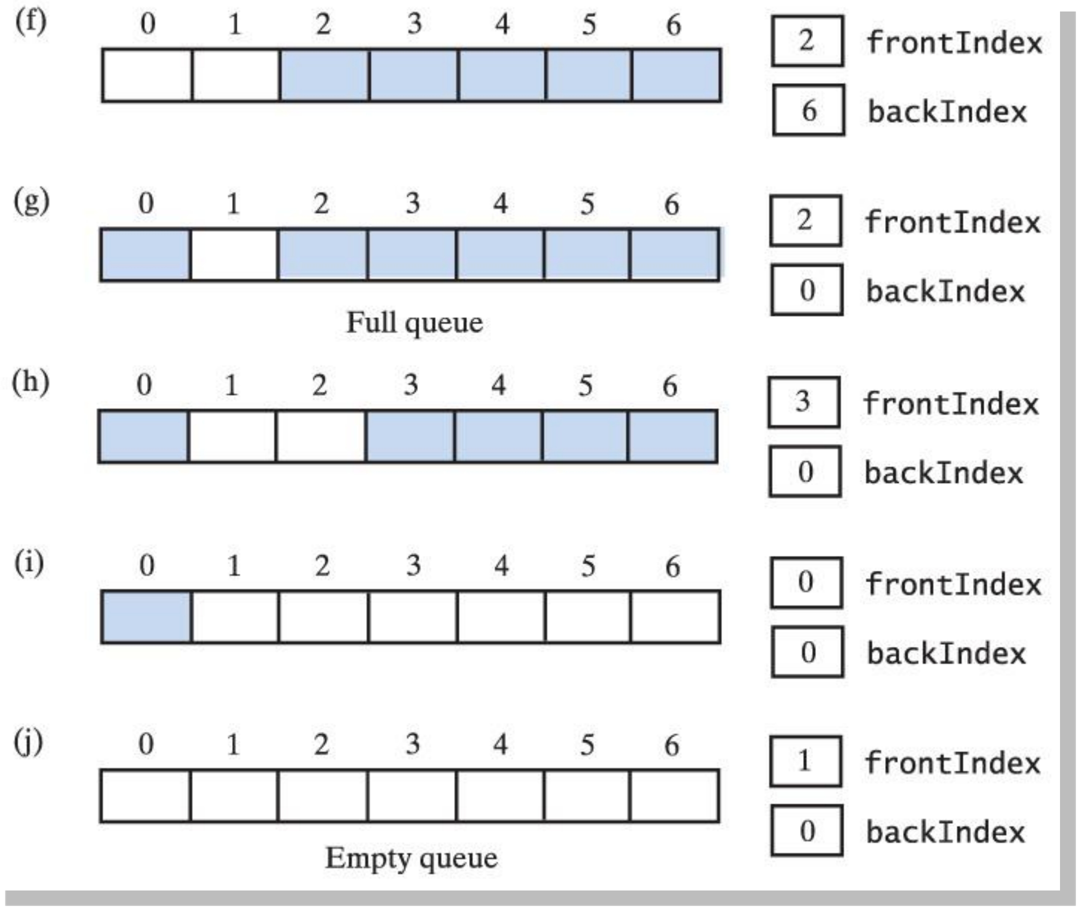
Allows us to distinguish between empty and full queue

A Circular Array with One Unused Location

Method 3: Circular Array

Fig. 24-8 (cont'd.)

A seven-location circular array that contains at most six entries of a queue.



Method 3:
Circular Array

Method `isEmpty()`

- The queue is empty if

```
((backIndex + 1) % array.length) == frontIndex
```

Checking for full array

Method 3:
Circular Array

- The queue is full if

```
((backIndex + 2) % array.length) == frontIndex
```

Method 3: Circular Array

Implementation of method `doubleArray()` in a circular array

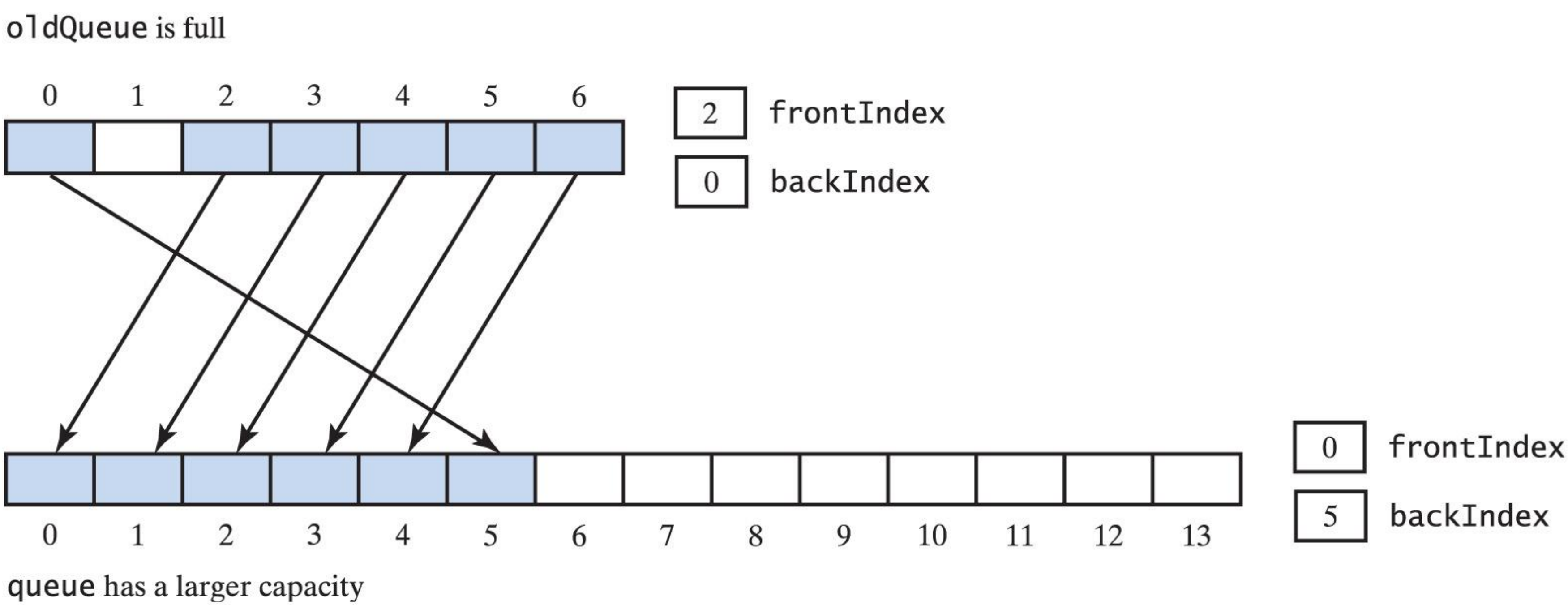


Fig. 24-10 Doubling the size of an array-based queue

Self Recap

The 3 array implementations covered today:

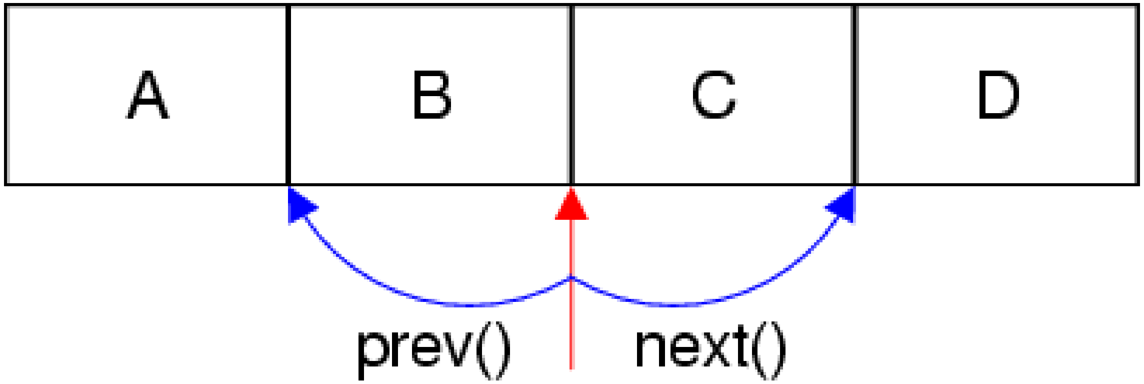
- Linear array with *fixed* front
- Linear array with *dynamic* front
- *Circular* array

Sample Code

- Chapter4\adt\
  - **QueueInterface.java**
  - **ArrayQueue.java**
  - **CircularArrayQueue.java**
- Chapter4\entity\
  - **SharePortfolio.java**
  - **SharePurchase.java**
- Chapter4\client\
  - **SharePortfolio Driver.java**

java.util.Iterator

Iterators



Iterators (1)

- What if you need to go through the entries of a collection in order, one at a time?
- An iterator
  - is an object that enables you to *traverse* a collection of data, beginning with the first entry.
  - **acts like a cursor or pointer**, moving about on a data structure and locating individual elements for access.
  - is a software design pattern that abstracts the process of scanning through a collection of elements one element at a time.

Iterators (2)

- During one complete iteration, each entry is considered once
- Iterator may be manipulated
  - Check whether next entry exists
  - Asked to advance to next entry
  - Give a reference to current entry
  - Modify the list as you traverse it

Java's Iterator Interfaces

- As iteration is such a common operation, Java provides 2 interfaces for iterators for a uniform way for traversing elements in various types of collections:
  - **`Iterator`**
  - **`ListIterator`**
- These interfaces provide a uniform way for traversing elements in various types of collections.

  (Recall: Collections include list, stack, queue, *etc.*)

`java.util.Iterator`

- This interface specifies a generic type for entries
- Includes 3 method headers:

`hasNext`	Checks if next entry exists .
`next`	Returns next entry and advances iterator to the next entry. Throws `NoSuchElementException` if there are no more elements.
`remove`	Removes the entry that was returned by the last call to **`next()`.**

<<interface>>

java.util.Iterator<T>

+hasNext(): boolean

+next(): T

+remove(): void

An Inner Class Iterator (1)

- The iterator class is defined as an *inner class* of the collection ADT
  - Thus, it has direct access to the ADT's data fields.

Outer/Enclosing Class

Inner/Nested Class

```
public class ArrayQueue<T> implements QueueInterface<T> {
  private T[] array;
  private final static int frontIndex = 0;
  private int backIndex;
  . . .
  private class ArrayQueueIterator implements Iterator<T> {
     private int nextIndex = 0;
     public boolean hasNext() {
        return nextIndex <= backIndex;
      }
     public T next() {
        if (hasNext()) {
          T nextEntry = array[nextIndex];
          nextIndex++; // advance iterator
          return nextEntry;
        } else {
          return null;
        }
      }
    }
```

An Inner Class Iterator (2)

- Then, provide a public method that returns an iterator to the collection:

```
public interface QueueInterface<T> {
    public Iterator<T> getIterator();
    . . .
}
```

- **getIterator()** includes a call to the inner class iterator's constructor, which enables the client to create an iterator:

```
public class ArrayQueue<T> . . . {
    . . .
    public Iterator<T> getIterator() {
      return new ArrayQueueIterator();
    }
    . . .
}
```

Example of How to Use Iterator in Client Program

```java
package client;

import adt.QueueInterface;
import adt.ArrayQueue;
import java.util.Iterator;

public class TestIterator2{
    public static void main(String[] args) {
        QueueInterface<Integer> q = new ArrayQueue<>();

        q.enqueue(10);
        q.enqueue(20);
        q.enqueue(50);
        q.enqueue(100);
        q.enqueue(60);
        q.enqueue(35);

        Iterator<Integer> iterator = q.getIterator();

        int count = 0;
        int num = 0;

        while(iterator.hasNext()){
            num = iterator.next();
            System.out.println(num);
            if(num > 50)
                count++;
        }

        System.out.println("No of items with values > 50 is " + count);
    }
}
```

Output - Chapter4 (run)

```
run:
10
20
50
100
60
35
No of items with values > 50 is 2
BUILD SUCCESSFUL (total time: 0 seconds)
```

Sample Code

(a) `Chapter4\adt\`

- **`QueueInterface.java`**
  - Contains the additional abstract method **`getIterator()`** which returns an iterator to the queue
- **`ArrayQueue.java`**
  - A class that implements the interface `QueueInterface`.

(b) `Chapter4\adt\`**`SharePortfolio.java`**:

- Contains the additional methods
  - **`countTotalUnitShares()`** which returns the current number of units of shares in the portfolio, and
  - **`getSharePortfolioCapital()`** which returns the capital value in the portfolio

(b) `Chapter4\adt\`**`SharePortfolioDriver.java`**:

Learning Outcomes

You should now be able to

- Implement the ADTs list, stack and queue using arrays.
- Discuss the strengths and weaknesses of using arrays to implement the ADTs.
- Analyze the efficiency of the array implementations of the ADTs

References

- Carrano, F. M., 2019, Data Structures and Abstractions with Java, 5th edn, Pearson
- Liang, Y.D., 2018. Introduction to Java Programming and Data Structures.11th ed.United Kingdom:Pearson
- Malik DS and Nair PS, 2003, Data Structures using Java, Thomson Course Technology