Topic 10

Data Structures

ICT167 Principles of Computer Science

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OBJECTIVES

- Classify common Data Structures according to whether they are:
  - **linear** or allow **direct access**
  - **homogeneous** or **heterogeneous**
  - **static** or **dynamic**
- Describe **Lists, Queues**, **Stacks**, **Sets**
- List and describe the **methods** which you would expect to find in the following classes: **List**, **Queue**, **Stack**

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OBJECTIVES

- Describe the **difference between an array and an ArrayList object** in Java
- Understand generics (parameters for types) in Java
- Be able to use **an ArrayList** in a simple program
- Be able to use the **for-each** loop in Java
- Be able to use **a Stack** in a simple program

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OBJECTIVES

- Be able to use **a Queue** in a simple program
- List some of the concerns of an implementer of a Data Structure class

Reading:

Savitch Chapter 12.1 plus extra material

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DATA STRUCTURES

- Data structures are ways of collecting and organizing (a lot of) data into structures
- It is common to use a standard abstract data type (ADT) to manage a structured collection of data
  - Choose the ADT for the purpose
- There are many standard ADTs for data structures

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DATA STRUCTURES

- They vary according to:
  - Whether the data is arranged in a **linear** way (eg: an array) or a **non-linear** way (eg: a tree shape)
  - How access to data items is allowed (one at a time, first one first – **sequential access**, or some sort of indexing – **direct access**)
  - Whether the data items have to be of the same type (**homogeneous**) or can be mixed (**heterogeneous**)

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DATA STRUCTURES

- They vary according to:
  - Whether the data structure is **static** (of fixed size, known at compile time, eg: an array) or **dynamic** (can grow and shrink while program is running, eg: an ArrayList, a vector or a linked list)

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DATA STRUCTURES

- Programmers need to be familiar with many data structures in order to:
  - Choose the right one for the job
  - Find it in a library
  - Use it correctly
  - Implement it themselves

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DATA STRUCTURES

- In this unit we just get a basic idea of some common data structures
  - In later units you'll get to know many quite well
- We have already met a homogeneous, linear, direct access data structure of fixed length: the *array*
- Let us look at some others

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THE LIST ADT

- There is no precise agreement in the literature about what this is exactly
- General idea - it is a linear structure of varying length
- It is a collection of data stored sequentially
  - For example, a list of students, a list of courses, a list of books, a list of companies, etc can be stored using a list

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THE LIST ADT

- Often called linked list – a dynamic data structure commonly used in many programming languages
- Generally a list is homogeneous (i.e. each item in it is of the same type) but, as we will see, this is not very important in Java
- Some definitions allow only sequential access perhaps with the help of a cursor or list pointer

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THE LIST ADT

- So you can look at (or remove) the current item only and have to move the cursor forwards or backwards through the list to access other elements
- Other definitions allow direct access; i.e. you can do things with the *i*th element, for any (meaningful) value of *i*
  - Eg: the pre-defined class ArrayList available in java.util package

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THE LIST ADT

- A list (or linked list) consists of nodes
- Each node has a place for an element of data and a link (pointer) to another node
- In Java, each node is an object of a class that has two instance variables:
  - One for the data and one for the link
  - A pre-defined LinkedList is available in the java.util package

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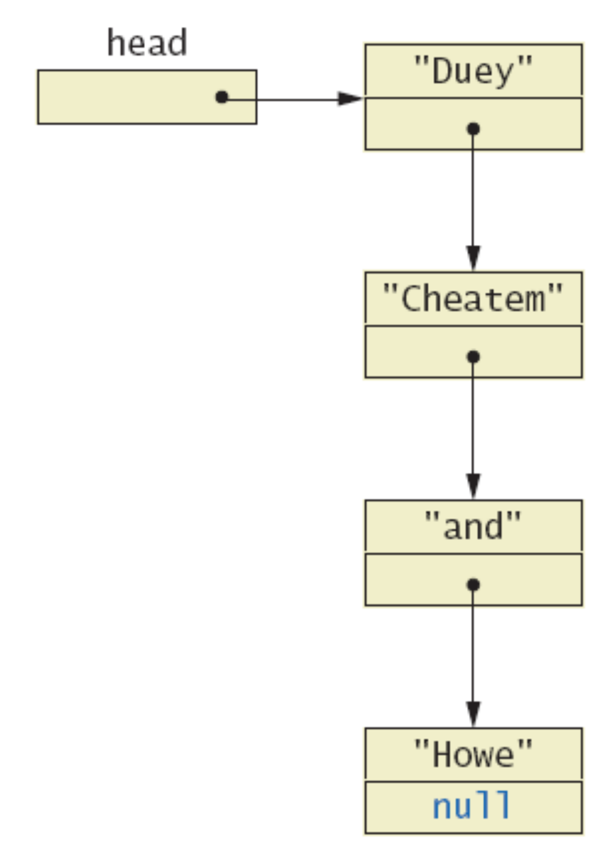
Figure from textbook



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THE LIST ADT

- In giving a definition of an ADT (eg: *list)*, you need to just specify what operations are available on it and say what they do
  - These are the methods which you would expect to find if someone sold you a library with a *list* class in it
  - These are methods which you would have to provide if you wanted to sell your own *list* class
  - These are the only operations which you would be allowed to use if an exam question asked you to accomplish a task using a *list*

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LIST OPERATIONS

- Here are some operations which you might expect to be available for a list of objects of type T (plus or minus a few)
- Eg: a list of **int**s, a list of **boolean**s, a list of **String**s, a list of Books

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LIST OPERATIONS

- Some constructors plus the following methods:

```
public void makeEmpty()
public int size() // returns size of list
public T elementAt(int index)
- returns the element at position index
public void setElementAt(int index,
                         T newValue)
- changes element at position index to newValue
```

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LIST OPERATIONS

`public void removeElementAt(int index)`

- removes element at position index and moves all the rest forward

`public void insertElementAt(int index, T newValue)`

- puts newValue in the list at index position and moves the rest along

`public void addElement(T newValue)`

- puts newValue at the end of list

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THE QUEUE ADT

- The Queue ADT is a homogeneous, linear structure but with restricted access
  - First-In-First-Out (FIFO) access order
- In a queue, insertions take place at the back (the tail) of a queue and deletions take place from the front (the head) of a queue

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THE QUEUE ADT

- Operations include constructors (to create a new empty queue with a certain capacity), plus the following:

```
public boolean isEmpty()
public boolean isFull()
public void enqueue(T newValue)
- puts newValue at the end of queue, also
  called append
```

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THE QUEUE ADT

```
public T dequeue()
```

- returns the front value and removes it from the queue, also called remove

```
public int size()
```

- returns the size of the queue

You may also find:

```
public T peek()
```

- returns top value without removing it from queue

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THE STACK ADT

- The Stack ADT is also a homogeneous, linear structure but with a different restricted access
  - Last-In-First-Out (LIFO) access order
- In a stack insertions and deletions take place only at the one end, referred to as the top of a stack

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THE STACK ADT

- Operations include constructors (to create a new empty stack with a certain capacity), plus the following:

```
public boolean isEmpty()
public boolean isFull()
public void push(T newValue)
- puts newValue at the top
public T pop()
- returns the top value and removes it from the
  stack
```

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THE STACK ADT

- Note that instead (or as well) you may find:

```
public void pop()
- removes top value from stack
and
public T peek()
- returns top value without removing it from
  the stack
```

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THE SET ADT

- The Set ADT is a non-linear data structure
- Only **one** copy of any element is allowed in the set
- Operations include constructors and the following:

```
public void makeEmpty()
public void add(T newValue)
- adds newValue if it is not there already
    (does nothing if it is there already)
```

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THE SET ADT

```
public void remove(T value)
- removes the only copy of value if it is there
public boolean isIn(T value)
- membership testing
```

- Other methods include: set union (+) and set intersection (*) which return a new set
- **Note:** check Java API and documentation for any data structure class which you use
- There are many variations on the above mentioned general ideas

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DATA STRUCTURES IN JAVA

- Many data structures are homogenous (often for efficiency of memory usage reasons)
- This creates problems for writers of library classes. Do they supply code for:
  - a class of queues of **int**s
  - another class of queues of **double**s
  - another class of queues of **String**s
  - another class of queues of Books, etc etc?

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DATA STRUCTURES IN JAVA

- In C++ the idea of parameterized classes is used
- Java also introduced parameterized classes – called ‘generics’ – in Java 5.0
- In Java the simple idea is to allow data structures to contain **Object**s

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DATA STRUCTURES IN JAVA

- Each data structure is homogeneous as every one of its elements is an Object
- But anything (almost) can go into any data structure as (almost) everything is a (type of) **Object**

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DATA STRUCTURES IN JAVA

- Until Java 5.0, there were two problems:
  - Primitive values (which are not Objects) have to be wrapped to allow them to be stored, and
  - Everything comes out of a data structure as an **Object** and you need to cast it back into its more specific type in order to call specific methods on it

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DATA STRUCTURES IN JAVA

- Since Java 5.0 (jdk1.5) and later versions, which allow **automatic boxing** and **unboxing** of primitive types, the above problems are of much less concern now

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THE CLASS ARRAYLIST

- In Java, arrays (alone) are set up as special built-in data structures, and they are static (fixed size)
- We know that we can have arrays of specific types including primitives
- However, once an array is created its size cannot be changed
  - Although it is possible to create a new larger array to replace the current array and copy its elements – it is awkward

THE CLASS ARRAYLIST

- A more elegant solution is to use an instance of the Java library class `ArrayList`
- `ArrayList` instances can be thought of as arrays that grow and shrink while a program is running
- However, the base type of an `ArrayList` instance must be a class type

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THE CLASS ARRAYLIST

- `ArrayList` is not automatically part of Java
- It is available as part of the `java.util` package and must be imported by your program

  ```
  import java.util.ArrayList;
  ```
- An instance of `ArrayList` is created in the same way as any other object except that its base type is specified using a new notation (called **generics**), as follows:

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THE CLASS ARRAYLIST

```
ArrayList<String> list = new
                    ArrayList<String>(20);
```

- The above creates and names an `ArrayList` object list which can store instances of class `String` and has initial capacity of 20 elements
- To create an `ArrayList` instance of default capacity (default capacity = 10):

```
ArrayList<String> list = new
              ArrayList<String>();
```

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THE CLASS ARRAYLIST

- The `ArrayList` class includes constructors:

  `ArrayList<Base_Type>()`

  `- constructs an empty list with initial capacity 10. The Base_Type must be a class type - i.e. it can not be a primitive type such as int or double`

  `ArrayList<Base_Type>(int initialCapacity)`

  `- constructs an empty list with the specified initial capacity. When the list needs to increase its capacity, the capacity doubles`

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THE CLASS ARRAYLIST

- Methods include:

```
void add(Base_Type obj)
```

- adds obj to the end of this list

```
void add(int index, Base_Type obj)
```

- inserts obj at the specified index position of this list. Shifts elements at subsequent positions to make room for the new entry by increasing their indices by 1

```
Base_Type get(int index)
```

- returns the element at the specified index position

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THE CLASS ARRAYLIST

`void set(int index, Base_Type obj)`

- replaces element at the position specified by index with the given obj in this list

`Base_Type remove(int index)`

- removes and returns the element at the specified index

`boolean remove(Object obj)`

- removes the first occurrence of obj in this list

`boolean contains(Object obj)`

- returns true if obj is in this list, otherwise returns false

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THE CLASS ARRAYLIST

`int indexOf(Object obj)`

- returns the index of the first occurrence of obj. Returns -1 if obj is not in the list

`void clear()`

- removes all of the elements from this list

`int size()`

- returns the size (number of elements) of the list

`void ensureCapacity(int n)`

- increases the capacity of this list, if necessary, to ensure that it can hold **n** elements

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THE CLASS ARRAYLIST

`void trimToSize()`

- trims the capacity of this list to be the list's current size

`boolean isEmpty()`

- determines whether the list is empty or not

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EXAMPLE

```
ArrayList<Integer> list = new
                  ArrayList<Integer>();
System.out.println("The initial size
       of list is:" + list.size());
for (int i=0;i < 15;i++)
   list.add(i*2+1);
   // autoboxing of int to wrapper Integer
System.out.println("\nThe numbers in
                       the list are:");
```

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EXAMPLE

```
int temp;
for (int i=0;i < list.size();i++){
   temp = list.get(i);
   // auto-unboxing of wrapper Integer to its
   // int value
   System.out.println(temp);
}
```

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FOR-EACH LOOP

- Java (jdk1.5) introduced another form of the `for` loop
- You can use this with a collection of data such as an array or an `ArrayList`
- It is called the `for-each` loop or `enhanced for` loop
- It enables the traversing of a complete array without using an index variable

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FOR-EACH LOOP

- For example:

```
int[] myList =
 {10,20,30,40,50,60,70,80,90,100};
for (int index : myList)
   System.out.println(index);
```

- This will display all the values from the array `myList` above

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FOR-EACH LOOP

- Similarly, the second `for` loop code from the previous example can be written using the `for-each` loop as follows:

```
for (int i : list){
    int temp = i;
    System.out.println(temp);
}
```

- Or even:

```
for (int i : list){
    System.out.println(i);
}
```

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ARRAYLIST VS ARRAY

- Arrays are fixed in size once they are created
  - Once you start putting values/objects in an array, you can not make it larger
- An `ArrayList` instance keeps increasing in size and capacity as you add more elements
- Size = actual number of elements in the list at the moment

ARRAYLIST VS ARRAY

- Capacity = the number of elements the list can currently hold (i.e. amount of memory currently reserved for the list)
  - Capacity can be explicitly increased and/or increases automatically anyway
- The base type of an array is specified when the array is declared
  - All elements of the array must be of the same type (i.e. arrays contain a fixed homogenous type of values including primitives)

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ARRAYLIST VS ARRAY

- The base type of an `ArrayList` instance is a class
- Arrays have convenient traditional [square bracket] notation
- `ArrayList` instances are objects with constructors and methods
- Arrays are stored more efficiently

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ARRAYLIST VS ARRAY

- `ArrayLists` are also implemented using arrays anyway (but that need not concern the client)
- Elements of an `ArrayList` move left or right during removal or insertion

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ARRAYLISTDEMO CLASS

```
import java.util.ArrayList;
import java.util.Scanner;
public class ArrayListDemo {
   public static void main(String[] args){
      ArrayList<String> toDoList = new
                            ArrayList<String>();
      System.out.println("Enter items
            for the list, when prompted.");
      boolean done = false;

      Scanner kbd = new Scanner(System.in);
```

ARRAYLISTDEMO CLASS

```
while (!done) {
    System.out.println("Type entry");
    String entry = kbd.nextLine( );
    toDoList.add(entry);
    System.out.print("More items for
                            the list?");
    String ans = kbd.nextLine( );
    if (!ans.equalsIgnoreCase("yes"))
        done = true;
} // end while
```

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ARRAYLISTDEMO CLASS

```
    System.out.println("List contains");
    int listSize = toDoList.size( );
    for (int position=0;
         position<listSize;position++)
         System.out.println(
             toDoList.get(position));
    /* Alternate code for displaying the list:
    System.out.println("The list contains:");
    for (String element : toDoList)
        System.out.println(element); */
  }// end main
}// end class
```

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ARRAYLISTDEMO CLASS

- Note that the above program will not compile under jdk 1.4 or earlier versions of Java because these versions did not allow generics

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STACKS IN JAVA

- There is a **Stack** class in the **java.util** package
- It is derived from the **Vector** class
- Its methods include:
  - empty()
  - peek()
  - pop()
  - push(E item)

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STACKS IN JAVA

```
// File: TestStackADT
/* Program to read in list of names and display the
list in reverse order */
import java.util.*;
class TestStackADT {
   public static void main(String[] args){
      Stack myStack <String> = new
                  Stack <String> ();
      String nameStr;
      boolean done = false;
```

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STACKS IN JAVA

```
System.out.println("Please enter the
                        list of names.");
System.out.println("'quit' to finish.");
System.out.print("Name:");
Scanner kbd = new Scanner(System.in);
nameStr = kbd.nextLine();
while(
!nameStr.equalsIgnoreCase("quit")){
   myStack.push(nameStr);
   System.out.print("Name:");
   nameStr = kbd.nextLine();
} // end while
```

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STACKS IN JAVA

```
    System.out.println("\nThe list in
                   reverse order is:");
    while (!myStack.empty()) {
        nameStr = myStack.pop();
        // typecast back to String required above
        System.out.println(nameStr);
    } // end while
    System.out.println("\nEnd of
                         Program - Bye.");
  }// end of main
}// end of class
```

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QUEUES AND OTHER ADTs IN JAVA

- Other data structure classes can be found in Java API, Java class libraries purchased from software developers or found free on the Internet
- Also check out software provided with text books for undergraduate data structures courses
- Once you have downloaded such code, compile it and javadoc it and it is ready to use

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QUEUES AND OTHER ADTs IN JAVA

- Note that you will have to obtain copyright clearance if you sell software which uses classes downloaded from other sources
- Java API has a `Queue` interface and a `LinkedList` class (in `java.util` package) which can be used to implement a simple queue
- However, it is easy to write your own `Queue` class based on the `ArrayList` class (covered in this topic), as follows:

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GENERICQUEUE CLASS

```
/**
 * File: GenericQueue.java
 * Implements a Generic queue class using the
   java.util.ArrayList class
 * Usage: To create a queue of strings, use:
 * GenericQueue<String> myQueue = new
                              GenericQueue<String>();
 * @author P S Dhillon
 */
```

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GENERICQUEUE CLASS

```
public class GenericQueue<E> {
   private java.util.ArrayList<E> list
      = new java.util.ArrayList<E>();
   public int size() {
      return list.size();
   }
   public E peek() {
      return list.get(0);
      // returns element at the head of
      // the queue without removing it
   }
```

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GENERICQUEUE CLASS

```
public boolean isEmpty() {
   return list.isEmpty();
}
public void append (E obj) {
   list.add(obj);
   // adds element to the end of the queue
}
```

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GENERICQUEUE CLASS

```
  public E remove() {
     E obj = list.get(0);
     // returns element at the head of the
     list.remove(0);
     // queue and removes it
     return obj;
  }
} // end GenericQueue class
```

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EXAMPLE USE OF QUEUE CLASS

- **How bad is the queue at the cinema?**
- **Simulation using the Queue ADT**
- Purpose:
  - Simulate waiting in the queue for 30 minutes and produce a report consisting of:
    - Number of paid customers for movie A
    - Number of paid customers for movie B
    - Number of customers turned away because the queue was too long

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EXAMPLE USE OF QUEUE CLASS

- Given:
  - One ticket office with one queue
  - Average time to serve one customer is 10 seconds
  - Probability of a new customer arriving during the 10 second interval is 0.7 (70%)
  - Maximum length of queue is 10

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SIMULATION

- A QUEUE OF BOX OFFICE CUSTOMERS
- Pseudocode for the main loop:

```
Loop 180 times
   Customer Service:
      if the queue is not empty
      serve the person at the front of
      the queue
      increment count of the film chosen
```

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SIMULATION

```
Customer Arrival:
   generate random probability for
another arrival
   if the probability is > 70%
      there is no arrival
   else
      if the queue has length 10
         the customer turns away
         increment turnedAway counter
```

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SIMULATION

```
        else
            select a film for customer
            and place them in the queue
endloop
```

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CINEMA QUEUE CLASS

```
/** CinemaQueue.java
 * This program simulates movie cinema queue,
 * where customers attend movie A or movie B
 * Uses the GenericQueue class
 * ---------------------------------------- */
public class CinemaQueue {
   public static void main(String[] args){
      GenericQueue<Character> cineQ =
     new GenericQueue<Character>();
      int  timeUnit;
      int  turnedAway = 0;
```

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CINEMA QUEUE CLASS

```
int  numA = 0; int numB = 0;
char movieChoice; // 'A' or 'B'
for (timeUnit=1;timeUnit <= 180;
                         timeUnit++){
   if ( !(cineQ.size( ) == 0)) {
      Character c = (Character)
                   (cineQ.remove());
      // removes customer from queue
      // casts Object to wrapper Character
```

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CINEMA QUEUE CLASS

```
    movieChoice = c.charValue();
    // unwraps to char
    if ( movieChoice == 'A')
        numA++;
    else
        numB++;
} // end if
```

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CINEMA QUEUE CLASS

```
if ( Math.random( ) <= 0.7 ){
    if (cineQ.size( ) >= 10)
        turnedAway++;
    else {
    // select choice & place it in queue
        if (Math.random() <= 0.5)
            movieChoice = 'A';
        else
            movieChoice = 'B';
```

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CINEMA QUEUE CLASS

```
        cineQ.append( new
            Character(movieChoice));
            // enqueue the wrapped char
        } // end else
    } // end if
} // end for loop
```

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CINEMA QUEUE CLASS

```
System.out.println("Movie A
          customers: " + numA);
System.out.println("Movie B
          customers: " + numB);
System.out.println("Number turned
          away: " + turnedAway);
} // end main()
} // end class
```

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IMPLEMENTING DATA STRUCTURE ADTs

- There is a lot of work done on implementing these classes
  - Many tricky methods are known to allow data structures to be implemented efficiently and you may study this in future units
- Often the classes have instance variables including an array to actually store all the elements plus perhaps some extra variables to record the state of the structure

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IMPLEMENTING DATA STRUCTURE ADTs

- In implementing such classes the programmer needs to consider:
  - Efficiency issues, size of memory used, speed of operations
  - The actual way that the structure will be used (eg: some implementations of lists are better if we often want to remove items from the middle while other implementations are better if we never want to do that)

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IMPLEMENTING DATA STRUCTURE ADTs

- In implementing such classes the programmer needs to consider:
  - Multi-threading (you must protect a data structure if there may be several parallel attempts to use it)
  - Making the style of usage and the method names fit in with standard usage

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