33. Dynamic Data Structures

Java

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Introduction

Introduction

- **Data Structure**
  - A data structure is a collection of data organized in some fashion.
  - A data structure not only stores data, but also supports the operations for accessing and manipulating data in the structure.
- **Types of data structures:**
  - **Fixed-size data structures**
    - such as one-dimensional and multidimensional arrays.
  - **Dynamic data structures**
    - that grow and shrink at execution time.

Arrays

- An array is a data structure that holds a collection of data in sequential order.
- You can find the size of the array, and store, retrieve, and modify data in the array.
- Arrays are simple and easy to use, but they have two limitations:
  - (1) once an array is created, its size cannot be altered;
  - (2) an array does not provide adequate support for insertion and deletion operations.

Classic Dynamic Data Structures

- Classic dynamic data structures:
  - **Linked Lists**
  - **Stacks**
  - **Queues**
  - **Trees**

Classic Dynamic Data Structures

- **Linked lists**
  - are collections of data items "linked up in a chain insertions and deletions can be made anywhere in a linked list.
- **Stacks**
  - are important in compilers and operating systems; insertions and deletions are made only at one end of a stacks top.

Classic Dynamic Data Structures

- **Queues**
  - represent waiting lines; insertions are made at the back (also referred to as the **tail**) of a queue and deletions are made from the front (also referred to as the **head**).
- **Trees**
  - is a data structure that supports searching, sorting, inserting, and deleting data efficiently.

Object-Oriented Data Structure

- In object-oriented thinking, a data structure is **an object** that stores other objects, referred to as data or elements.
- Some people refer to data structures as container objects or **collection objects**.
- To define a data structure is essentially to declare a class.
- The class for a data structure should use data fields to store data and provide methods to support such operations as insertion and deletion.

Object-Oriented Data Structure

- To create a data structure is therefore to create an instance from the class.
- You can then apply the methods on the instance to manipulate the data structure, such as inserting an element into the data structure or deleting an element from the data structure.

Introduction

- Java Collections Framework
  - Contain prepackaged data structures, interfaces, algorithms for manipulating those data structures
  - With collections, programmers use existing data structures, without concern for how they are implemented.
  - This is a example of code reuse.
  - Programmers can code faster and can expect excellent performance, maximizing execution speed and minimizing memory consumption.

Introduction

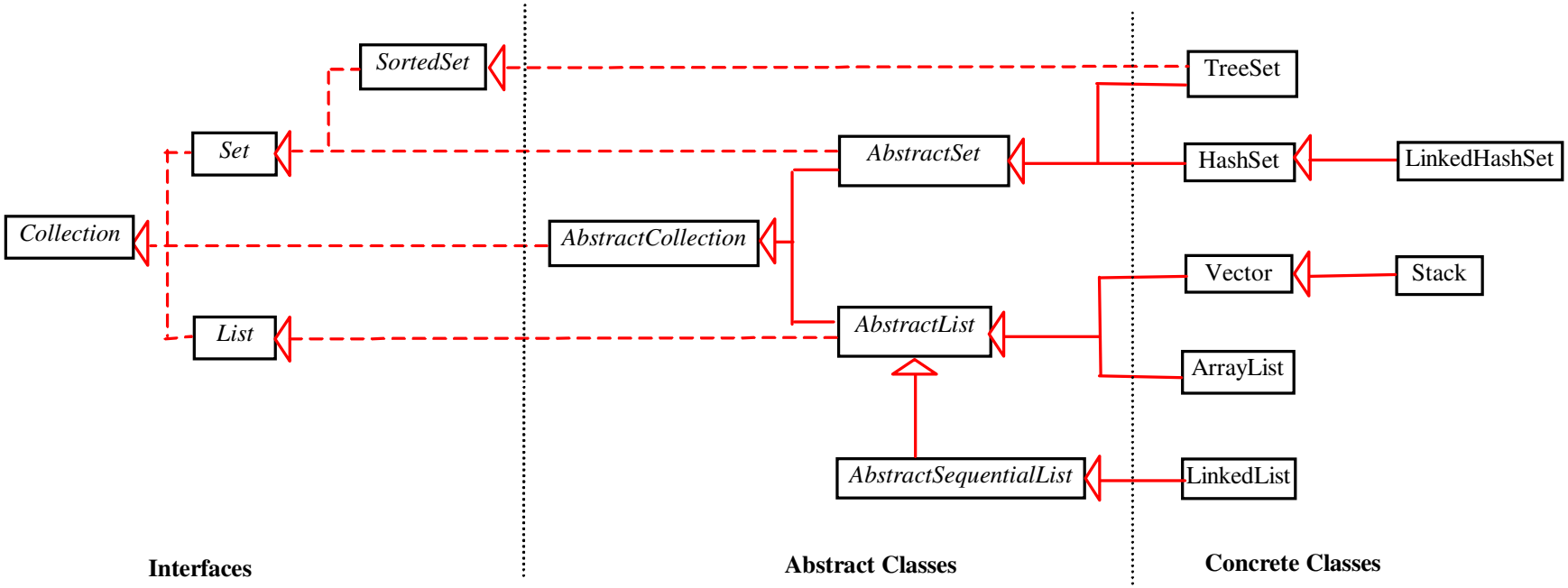
- Collection
  - Data structure (object) that can hold references to other objects
- Collections Framework Interfaces
  - declare operations for various collection types
  - Provide high-performance, high-quality implementations of common data structures
  - Enable software reuse

Collections Framework Interfaces

- **Collection**
  - The root interface in the collections hierarchy from which interfaces Set, Queue and List are derived.
- **List**
  - An ordered collection that can contain duplicate elements.
- **Queue**
  - Typically a first-in, first-out collection that models a waiting line; other orders can be specified.
- **Set**
  - A collection that does not contain duplicates.
- **Map**
  - Associates keys to values and cannot contain duplicate keys.

Collections Framework Interfaces

- Set and List are subinterfaces of Collection



Interfaces and Classes

Interface	implemented by class	Description
List	ArrayList	a linked list data structure
List	LinkedList	a linked list data structure
List	Stack	a stack data structure
Queue	PriorityQueue	A queue data structure
Set	HashSet	Stores unique elements in a hash table

ArrayList Class

Lists

- A list is a popular data structure for storing data in sequential order.
- For example, a list of students, a list of available rooms, a list of cities, and a list of books can all be stored using lists.
- The operations listed below are typical of most lists:
  - Retrieve an element from a list.
  - Insert a new element to a list.
  - Delete an element from a list.
  - Find how many elements are in a list.
  - Find whether an element is in a list.
  - Find whether a list is empty.

Lists

- **List**
  - A list is can contain duplicate elements
  - Sometimes called a **sequence**
  - List indices are zero based (i.e., the first element's index is zero)
  - Classes
    - ArrayList: is resizable-array
    - LinkedList : is resizable-array

ArrayList Class

- You can create an array to store objects.
- But the array's size is fixed once the array is created.
- Java provides the **ArrayList** class that can be used to store an unlimited number of objects.
- **ArrayList** is a class of **java.util**.
- **Autoboxing** occurs when you add a primitive type to a **ArrayList**

ArrayList Class

- +ArrayList()
  - Creates an empty list.
- +add(o: Object) : void
  - Appends a new element o at the end of this list.
- +add(index: int, o: Object) : void
  - Adds a new element o at the specified index in this list.
- +clear(): void
  - Removes all the elements from this list.
- +contains(o: Object): boolean
  - Returns true if this list contains the element o.

ArrayList Class

- +get(index: int) : Object
  - Returns the element from this list at the specified index.
- +indexOf(o: Object) : int
  - Returns the index of the first matching element in this list.
- +isEmpty(): boolean
  - Returns true if this list contains no elements.
- +lastIndexOf(o: Object) : int
  - Returns the index of the last matching element in this list.

ArrayList Class

- +remove(o: Object): boolean
  - Removes the element o from this list.
- +size(): int
  - Returns the number of elements in this list.
- +remove(index: int) : Object
  - Removes the element at the specified index.
- +set(index: int, o: Object) : Object
  - Sets the element at the specified index.

ArrayList Class

- Example 1:
  - TestArrayList.java
  - GeometricObject.java
  - Circle.java

- You will get a compilation warning “unchecked operation” Ignore it.

ArrayList Class

- The output:

```
List size? 6
Is Toronto in the list? true
The location of New York in the list? 1
Is the list empty? false
London Beijing Paris Hong Kong Singapore
The area of the circle? 12.566370614359172
```

ArrayList Class

- Example 2:
  - TestArrayList2.java

- ArrayList:
- MAGENTA RED WHITE BLUE CYAN

- ArrayList after calling removeColors:
- MAGENTA CYAN

ArrayList Class

- Example 3:
  - TestArrayList3.java

- The output:

  List is: 7

  List is: 7 11

  List is: 12 7 11

  List is: 12 11

Performance Tip

- An array can be declared to contain more elements than the number of items expected, but this wastes memory.
- Linked lists provide better memory utilization in these situations.
- Linked lists allow the program to adapt to storage needs at runtime.

Performance Tip

- Insertion into a linked list is fast—only two references have to be modified (after locating the insertion point).
- All existing node objects remain at their current locations in memory.

Performance Tip

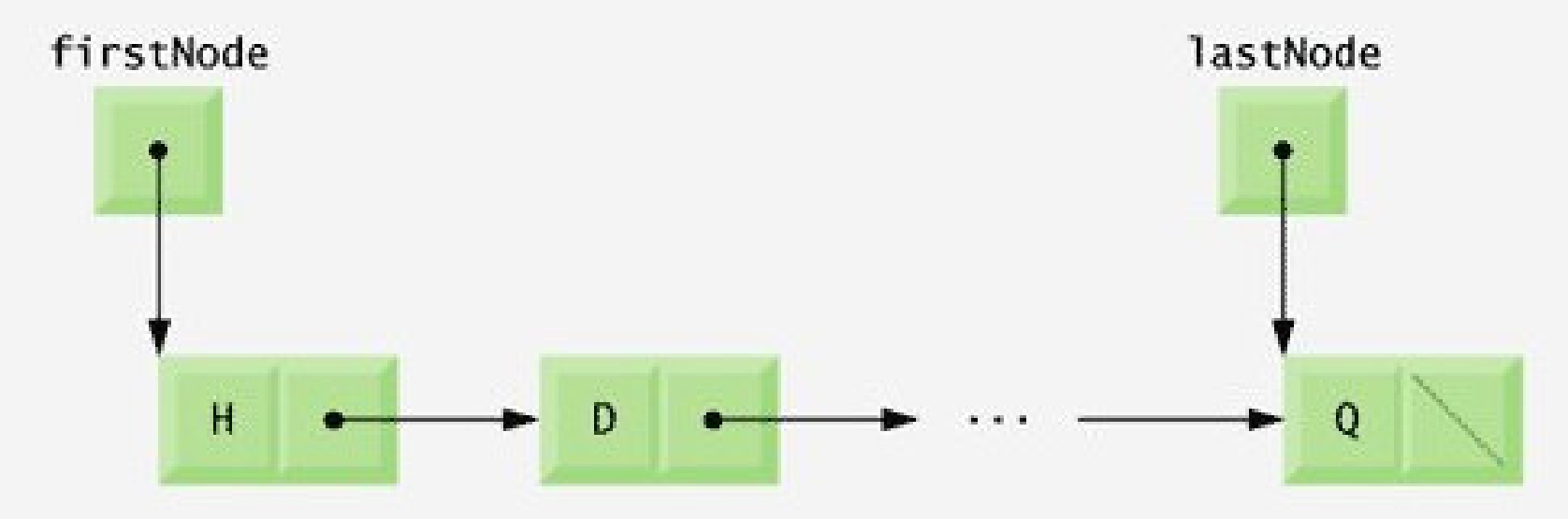
- Insertion and deletion in a sorted array can be time consuming
- All the elements following the inserted or deleted element must be shifted appropriately.

Performance Tip

- Normally, the elements of an array are contiguous in memory.
- This allows immediate access to any array element, because its address can be calculated directly as its offset from the beginning of the array.
- Linked lists do not afford such immediate access to their elements
- An element can be accessed only by traversing the list from the front (or from the back in a doubly linked list).

Linked Lists

- Linked list graphical representation



Generics

Generics

- It would be nice if we could write a single sort method that could sort the elements in an Integer array, a String array or an array of any type that supports ordering (i.e., its elements can be compared).
- It would also be nice if we could write a single Stack class that could be used as a Stack of integers, a Stack of floating-point numbers, a Stack of Strings or a Stack of any other type.

Generics

- It would be even nicer **if we could detect type mismatches at compile** time known as compile-time type safety.
- For example, if a Stack stores only integers, attempting to push a String on to that Stack should issue a compile-time error.
- **Generics** provides the means to create the general models mentioned above.

Generics

- Generics
  - Provide compile-time type safety
    - Catch invalid types at compile time
  - Generic methods
    - A single method declaration
  - Generic classes
    - A single class declaration

Generics

- Note that ArrayList is a generic class, so we are able to specify a type argument (String in this case) to indicate the type of the elements in each list.

- Example:
  - TestArrayList4.java

LinkedList Class

LinkedList Class

- LinkedLists can be used to create stacks, queues, trees and deques (double-ended queues, pronounced “decks”).
- The collections framework provides implementations of some of these data structures.

Iterator

- It is common in object-oriented programming to declare an iterator class that can traverse all the objects in a collection, such as an array or an ArrayList or LinkedList
- For example, a program can print an LinkedList of objects by creating an iterator object and using it to obtain the next list element each time the iterator is called.
- Iterators often are used in polymorphic programming to traverse a collection that contains references to objects from various levels of a hierarchy.

LinkedList Class

- ListTest.java
  - The program creates two LinkedLists that contain Strings.
  - The elements of one List are added to the other.
  - Then all the Strings are converted to uppercase, and
  - a range of elements is deleted

LinkedList Class

- The program output:

```
list1:
black yellow green blue violet silver gold white brown blue gray silver

list1:
BLACK YELLOW GREEN BLUE VIOLET SILVER GOLD WHITE
    BROWN BLUE GRAY SILVER

Deleting elements 4 to 6...
list1:
BLACK YELLOW GREEN BLUE WHITE BROWN BLUE GRAY SILVER

Reversed List:
SILVER GRAY BLUE BROWN WHITE BLUE GREEN YELLOW BLACK
```

Common Programming Error

- If a collection is modified by one of its methods after an iterator is created for that collection, the iterator immediately becomes invalid—any operations performed with the iterator after this point throw ConcurrentModificationExceptions.
- For this reason, iterators are said to be “fail fast.”

LinkedList Class

- static method asList of class Arrays
  - Allow programmer to manipulate the array as if it were a list
  - Any modification made through the List view change the array
  - Any modification made to the array change the List view

LinkedList Class

- UsingToArray.java
  - The program calls method asList to create a List view of an array, which is then used for creating a LinkedList object,
  - adds a series of strings to a LinkedList and
  - calls method toArray to obtain an array containing references to the strings.
  - Notice that the instantiation of LinkedList indicates that LinkedList is a generic class that accepts one type argumentString, in this example.

LinkedList Class

- The program output:

```
colors:
cyan
black
blue
yellow
green
red
pink
```

Common Programming Error

- If the number of elements in the array is smaller than the number of elements in the list on which toArray is called, a new array is allocated to store the list's elements
- If the number of elements in the array is greater than the number of elements in the list, the elements of the array (starting at index zero) are overwritten with the list's elements. Array elements that are not overwritten retain their values.

Collections Class

Collections Class

- Collections class provides set of algorithms, implemented as static methods, include:
  - sort
    - Sorts the elements of a List.
  - binarySearch
    - Locates an object in a List.
  - reverse
    - Reverses the elements of a List.
  - shuffle
    - Randomly orders a List's elements.
  - fill
    - Sets every List element to refer to a specified object.
  - copy
    - Copies references from one List into another.

Collections Class

- min
  - Returns the smallest element in a Collection.
- max
  - Returns the largest element in a Collection.
- addAll
  - Appends all elements in an array to a collection.
- frequency
  - Calculates how many elements in the collection are equal to the specified element.
- disjoint
  - Determines whether two collections have no elements in common.

Algorithm sort

- sort
  - Sorts List elements
    - Order is determined by natural order of elements' type
- Sorting in ascending order
  - Collections method sort
- Sorting in descending order
  - Collections static method reverseOrder

Algorithm sort

- Sort1.java
  - uses algorithm sort to order the elements of a List in ascending order.
  - Recall that List is a generic type and accepts one type argument that specifies the list element type

- The program output:

```
Unsorted array elements:
[Hearts, Diamonds, Clubs, Spades]
Sorted array elements:
[Clubs, Diamonds, Hearts, Spades]
```

Sorting in Descending Order

- Sort2.java
  - sorts the same list of strings in descending order.
  - The static Collections method reverseOrder returns a object that orders the collection's elements in reverse order. It is a parameter for sort method.
- The program output:

```
Unsorted array elements:
[Hearts, Diamonds, Clubs, Spades]
Sorted list elements:
[Spades, Hearts, Diamonds, Clubs]
```

Algorithm shuffle

- ShuffleTest.java
  - In this program we use algorithm shuffle to shuffle a deck of Card objects that might be used in a card game simulator.
- The program output:

```
Array elements:
[Hearts, Diamonds, Clubs, Spades]
Shuffled list elements:
[Spades, Clubs, Diamonds, Hearts]
```

Algorithm reverse, fill, copy, max and min

- reverse
  - Reverses the order of List elements
- fill
  - Overwrites elements in a List with a specified value.
  - The fill operation is useful for reinitializing a List.
- copy
  - Creates copy of a List
  - takes two arguments a destination List and a source List
  - Each source List element is copied to the destination List
  - The destination List must be at least as long as the source List; otherwise, an IndexOutOfBoundsException occurs.
  - If the destination List is longer, the elements not overwritten

Algorithm reverse, fill, copy, max and min

- max
  - Returns largest element in List
  - Operate on any Collection
- min
  - Returns smallest element in List
  - Operate on any Collection

Algorithm1.java

- Algorithms1.java
  - demonstrates the use of algorithms reverse, fill, copy, min and max.
- The program output:

```
Initial list:
The list is: P C M
Max: P  Min: C

After calling reverse:
The list is: M C P
Max: P  Min: C

After copying:
The list is: M C P
Max: P  Min: C

After calling fill:
The list is: R R R
Max: R  Min: R
```

Algorithm binarySearch

- The binarySearch algorithm locates an object in a List (i.e., a LinkedList or an ArrayList).
- If the object is found, its index is returned. If the object is not found, binarySearch returns a negative value.
- Algorithm binarySearch determines this negative value by first calculating the insertion point and making its sign negative.
- Then, binarySearch subtracts 1 from the insertion point to obtain the return value, which guarantees that method binarySearch returns positive numbers (>=0) if and only if the object is found.

Algorithm binarySearch

- If multiple elements in the list match the search key, there is no guarantee which one will be located first.
- BinarySearchTest.java
  - uses the binarySearch algorithm to search for a series of strings in an ArrayList.

Algorithm binarySearch

- The program output:

```
Sorted list: [black, blue, pink, purple, red, tan, white, yellow]

Searching for: black
Found at index 0

Searching for: red
Found at index 4

Searching for: pink
Found at index 2

Searching for: aqua
Not Found (-1)

Searching for: gray
Not Found (-3)

Searching for: teal
Not Found (-7)
```

Algorithms addAll, frequency and disjoint

- addAll
  - Insert all elements of **an array** into a collection
  - Takes two arguments, a Collection into which to insert the new element(s) and an array that provides elements to be inserted
- frequency
  - Calculate the number of times a specific element appear in the collection
  - Takes two arguments a Collection to be searched and an Object to be searched for in the collection
- disjoint
  - Algorithm disjoint takes two Collections and returns true if they have no elements in common

Algorithms addAll, frequency and disjoint

- Algorithms2.java
  - demonstrates the use of algorithms addAll, frequency and disjoint.
- The program output:

```
Before addAll, list2 contains:
black red green

After addAll, list2 contains:
black red green red white yellow blue

Frequency of red in list2: 2

list1 and list2 have elements in common
```

Stack Class

Stacks

- Stacks
  - A stack is a constrained version of a linked list
  - The link member in the bottom (i.e., last) node of the stack is set to null to indicate the bottom of the stack.
  - **Last-In, First-Out (LIFO)** data structure
    - Method push adds a new node to the top of the stack
    - Method pop removes a node from the top of the stack and returns the data from the popped node
  - **Program execution stack**
    - Holds the return addresses of calling methods
    - Also contains the local variables for called methods

Stack Class

- Stack class in the Java utilities package java.util implements stack data structure
- Class Stack stores references to objects
- Autoboxing occurs when you add a primitive type to a Stack
- Class Stack extends class Vector class to implement a stack data structure.

Stack Class

- Example 1:
  - TestStack.java
- The output:

```
Stack is: -1
Stack is: -1 0
Stack is: -1 0 1
Stack is: -1 0 1 5
5 popped
Stack is: -1 0 1
1 popped
Stack is: -1 0
```

Stack Class

- Example 2:
  - TestStack2.java
- The output:

stack contains: 12 (top)
stack contains: 12 34567 (top)
stack contains: 12 34567 1.0 (top)
stack contains: 12 34567 1.0 1234.5678 (top)
1234.5678 popped
stack contains: 12 34567 1.0 (top)
1.0 popped
stack contains: 12 34567 (top)

Stack Class

- The constructor creates an empty Stack of type Number.
- Class Number (in package java.lang) is the superclass of most wrapper classes (e.g., Integer, Double) for the primitive types.
- By creating a Stack of Number, objects of any class that extends the Number class can be pushed onto the stack.

Stack Class

- Any integer literal that has the suffix L is a long value.
- An integer literal without a suffix is an int value.
- Similarly, any floating-point literal that has the suffix F is a float value.
- A floating-point literal without a suffix is a double value.

Stack Class

- Because Stack extends Vector, all public Vector methods can be called on Stack objects, even if the methods do not represent conventional stack operations.
- For example, Vector method add can be used to insert an element anywhere in a stack—an operation that could “corrupt” the stack.
- When manipulating a Stack, only methods push and pop should be used to add elements to and remove elements from the Stack, respectively.

PriorityQueue Class

PriorityQueue Class

- Queue
  - Similar to a checkout line in a supermarket
  - **First-In, First-Out (FIFO)** data structure
    - Enqueue inserts nodes at the tail (or end)
    - Dequeue removes nodes from the head (or front)
  - Used to support print spooling
    - A spooler program manages the queue of printing jobs

PriorityQueue Class

- Interface Queue,
  - extends interface Collection and provides additional operations for inserting, removing and inspecting elements in a queue.
- Class PriorityQueue,
  - one of the classes that **implements** the Queue interface, orders elements by their natural ordering
  - When adding elements to a PriorityQueue, the elements are inserted in priority order such that the highest-priority element (i.e., the largest value) will be the first element removed from the PriorityQueue.

PriorityQueue Class

- The common PriorityQueue operations are
  - **offer** to insert an element at the appropriate location based on priority order
    - Method offer throws a NullPointException if the program attempts to add a null object to the queue.
  - **poll** to remove the highest-priority element of the priority queue (i.e., the head of the queue),
  - **peek** to get a reference to the highest-priority element of the priority queue (without removing that element),
  - **clear** to remove all elements in the priority queue and
  - **size** to get the number of elements in the priority queue.

PriorityQueue Class

- PriorityQueueTest.java
  - demonstrates the PriorityQueue class.

- The program output:

  Polling from queue: 3.2 5.4 9.8

HashSet Class

Sets Class

- A Set is a Collection that contains unique elements (i.e., no duplicate elements), including:
  - HashSet
    - Stores elements in hash table
  - TreeSet
    - Stores elements in tree

HashSets Class

- HashSetTest.java
  - Recall that both List and Collection are generic types, so this program creates a List that contains String objects, and
  - It passes a Collection of Strings to method printNonDuplicates.

- The program output:

ArrayList: [red, white, blue, green, gray, orange, tan, white, cyan, peach, gray, orange]

Nonduplicates are:

orange green white peach gray cyan red blue tan

References

References

- H. M. Deitel and P. J. Deitel, **Java™ How to Program**, Sixth Edition, Prentice Hall, 2005. (Chapter 17 & Chapter 19)
- Y. Daniel Liang, **Introduction to Java Programming**, Sixth Edition, Pearson Education, 2007. (Chapter 21)

The End