19

Collections

I think this is the most extraordinary collection of talent, of human knowledge, that has ever been gathered together at the White House—with the possible exception of when Thomas Jefferson dined alone.

— John F. Kennedy

The shapes a bright container can contain!

— Theodore Roethke

Journey over all the universe in a map.

— Miguel de Cervantes

Not by age but by capacity is wisdom acquired.

— Titus Maccius Plautus

It is a riddle wrapped in a mystery inside an enigma.

— Winston Churchill

OBJECTIVES

In this chapter you will learn:

- What collections are.
- To use class `Arrays` for array manipulations.
- To use the collections framework (prepackaged data structure) implementations.
- To use collections framework algorithms to manipulate (such as `search`, `sort` and `fill`) collections.
- To use the collections framework interfaces to program with collections polymorphically.
- To use iterators to “walk through” a collection.
- To use persistent hash tables manipulated with objects of class `Properties`.
- To use synchronization and modifiability wrappers.

Outline

Outline

19.1 Introduction

- **Java collections framework**
  - **Contain prepackaged data structures, interfaces, algorithms**
  - **Use generics**
  - **Use existing data structures**
    - **Example of code reuse**
  - **Provides reusable componentry**

19.2 Collections Overview

- **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**
  - **Enhanced with generics capabilities in J2SE 5.0**
    - **Compile-time type checking**

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

Fig. 19.1 | Some collection framework interfaces.

19.3 Class `Arrays`

- Class **`Arrays`**
  - Provides **`static`** methods for manipulating arrays
  - Provides "high-level" methods
    - Method **`binarySearch`** for searching sorted arrays
    - Method **`equals`** for comparing arrays
    - Method **`fill`** for placing values into arrays
    - Method **`sort`** for sorting arrays

Outline

UsingArrays.java

(1 of 4)

Line 17

Line 18

```
1  // Fig. 19.2: UsingArrays.java
2  // Using Java arrays.
3  import java.util.Arrays;
4
5  public class UsingArrays
6  {
7     private int intArray[] = { 1, 2, 3, 4, 5, 6 };
8     private double doubleArray[] = { 8.4, 9.3, 0.2, 7.9, 3.4 };
9     private int filledIntArray[], intArrayCopy[];
10
11    // constructor initializes arrays
12    public UsingArrays()
13    {
14       filledIntArray = new int[ 10 ]; // create int array wi
15       intArrayCopy = new int[ intArray.length ];
16
17       Arrays.fill( filledIntArray, 7 ); // fill with 7s
18       Arrays.sort( doubleArray ); // sort doubleAr
19
20       // copy array intArray into array intArrayCopy
21       System.arraycopy( intArray, 0, intArrayCopy,
22          0, intArray.length );
23    } // end UsingArrays constructor
24
```

Use `static` method `fill` of class `Arrays` to populate array with 7s

Use `static` method `sort` of class `Arrays` to sort array's elements in ascending order

Use `static` method `arraycopy` of class `System` to copy array `intArray` into array `intArrayCopy`

```
25    // output values in each array
26    public void printArrays()
27    {
28       System.out.print( "doubleArray: " );
29       for ( double doubleValue : doubleArray )
30          System.out.printf( "%.1f ", doubleValue );
31
32       System.out.print( "\nintArray: " );
33       for ( int intValue : intArray )
34          System.out.printf( "%d ", intValue );
35
36       System.out.print( "\nfilledIntArray: " );
37       for ( int intValue : filledIntArray )
38          System.out.printf( "%d ", intValue );
39
40       System.out.print( "\nintArrayCopy: " );
41       for ( int intValue : intArrayCopy )
42          System.out.printf( "%d ", intValue );
43
44       System.out.println( "\n" );
45    } // end method printArrays
46
47    // find value in array intArray
48    public int searchForInt( int value )
49    {
50       return Arrays.binarySearch( intArray, value );
51    } // end method searchForInt
52
```

Use `static` method `binarySearch` of class `Arrays` to perform binary search on array

Outline

`UsingArrays.java`

(2 of 4)

Line 50

Outline

```
53    // compare array contents
54    public void printEquality()
55    {
56       boolean b = Arrays.equals( intArray, intArrayCopy );
57       System.out.printf( "intArray %s intArrayCopy\n",
58          ( b ? "==" : "!=" ) );
59
60       b = Arrays.equals( intArray, filledIntArray );
61       System.out.printf( "intArray %s filledIntArray\n",
62          ( b ? "==" : "!=" ) );
63    } // end method printEquality
64
65    public static void main( String args[] )
66    {
67       UsingArrays usingArrays = new UsingArrays();
68
69       usingArrays.printArrays();
70       usingArrays.printEquality();
71
```

Use `static` method `equals` of class `Arrays` to determine whether values of the two arrays are equivalent

Line 56 and 60

Outline

UsingArrays.java

(4 of 4)

```
72       int location = usingArrays.searchForInt( 5 );
73       if ( location >= 0 )
74          System.out.printf(
75             "Found 5 at element %d in intArray\n", location );
76       else
77          System.out.println( "5 not found in intArray" );
78
79       location = usingArrays.searchForInt( 8763 );
80       if ( location >= 0 )
81          System.out.printf(
82             "Found 8763 at element %d in intArray\n", location );
83       else
84          System.out.println( "8763 not found in intArray" );
85    } // end main
86 } // end class UsingArrays
```

Program output

```
doubleArray: 0.2 3.4 7.9 8.4 9.3
intArray: 1 2 3 4 5 6
filledIntArray: 7 7 7 7 7 7 7 7 7 7
intArrayCopy: 1 2 3 4 5 6

intArray == intArrayCopy
intArray != filledIntArray
Found 5 at element 4 in intArray
8763 not found in intArray
```

Common Programming Error 19.1

Passing an unsorted array to `binarySearch` is a logic error—the value returned is undefined.

19.4 Interface `Collection` and Class `Collections`

- Interface **`Collection`**
  - Root interface in the collection hierarchy
  - Interfaces **`Set`**, **`Queue`**, **`List`** extend interface **`Collection`**
    - **`Set`** – collection does not contain duplicates
    - **`Queue`** – collection represents a waiting line
    - **`List`** – ordered collection can contain duplicate elements
  - Contains *bulk operations*
    - Adding, clearing, comparing and retaining objects
  - Provide method to return an **`Iterator`** object
    - Walk through collection and remove elements from collection

Software Engineering Observation 19.1

`Collection` is used commonly as a method parameter type to allow polymorphic processing of all objects that implement interface `Collection`.

Software Engineering Observation 19.2

Most collection implementations provide a constructor that takes a `Collection` argument, thereby allowing a new collection to be constructed containing the elements of the specified collection.

19.4 Interface `Collection` and Class `Collections` (Cont.)

- Class `Collections`
  - Provides `static` methods that manipulate collections
    - Implement algorithms for searching, sorting and so on
  - Collections can be manipulated polymorphically
- Synchronized collection
- Unmodifiable collection

19.5 Lists

- List
  - Ordered `Collection` that can contain duplicate elements
  - Sometimes called a *sequence*
  - Implemented via interface `List`
    - `ArrayList`
    - `LinkedList`
    - `Vector`

Performance Tip 19.1

`ArrayLists` behave like `Vectors` without synchronization and therefore execute faster than `Vectors` because `ArrayLists` do not have the overhead of thread synchronization.

Software Engineering Observation 19.3

`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.

19.5.1 ArrayList and Iterator

- **ArrayList example**
  - Demonstrate Collection interface capabilities
  - Place two String arrays in ArrayLists
  - Use Iterator to remove elements in ArrayList

```
1  // Fig. 19.3: CollectionTest.java
2  // Using the Collection interface.
3  import java.util.List;
4  import java.util.ArrayList;
5  import java.util.Collection;
6  import java.util.Iterator;
7
8  public class CollectionTest
9  {
10    private static final String[] colors =
11       { "MAGENTA", "RED", "WHITE", "BLUE", "CYAN" };
12    private static final String[] removeColors =
13       { "RED", "WHITE", "BLUE" };
14
15    // create ArrayList, add Colors to it and manipulate it
16    public CollectionTest()
17    {
18       List< String > list = new ArrayList< String >();
19       List< String > removeList = new ArrayList< String >();
20
```

Outline

CollectionTest.java

(1 of 3)

Lines 18-19

Create `ArrayList` objects and assign their references to variable `list` and `removeList`, respectively

Outline

```
21      // add elements in colors array to list
22      for ( String color : colors )
23         list.add( color );
24
25      // add elements in removeColors to removeList
26      for ( String color : removeColors )
27         removeList.add( color );
28
29      System.out.println( "ArrayList: " );
30
31      // output list contents
32      for ( int count = 0; count < list.size(); count++ )
33         System.out.printf( "%s ", list.get( count ) );
34
35      // remove colors contained in removeList
36      removeColors( list, removeList );
37
38      System.out.println( "\n\nArrayList after calling removeColors: " );
39
40      // output list contents
41      for ( String color : list )
42         System.out.printf( "%s ", color );
43   } // end CollectionTest constructor
44
```

Use `List` method `add` to add objects to `list` and `removeList`, respectively

`CollectionTest.java`

Use `List` method `size` to get the number of `ArrayList` elements

Lines 23 and 27

Use `List` method `get` to retrieve individual element values

Line 33

Line 36

Method `removeColors` takes two `Collection`s as arguments; Line 36 passes two `List`s, which extends `Collection`, to this method

Outline

```
45    // remove colors specified in collection2 from collection1
46    private void removeColors(
47       Collection< String > collection1, Collection< String > collection2 )
48    {
49       // get iterator
50       Iterator< String > iterator = collection1.iterator();
51
52       // loop while collection has items
53       while ( iterator.hasNext() )
54
55          if ( collection2.contains( iterator.next() ) )
56             iterator.remove(); // remove current Color
57    } // end method removeColors
58
59    public static void main( String args[] )
60    {
61       new CollectionTest();
62    } // end main
63 } // end class CollectionTest
```

```
ArrayList:
MAGENTA RED WHITE BLUE CYAN

ArrayList after calling removeColors:
MAGENTA CYAN
```

Method `removeColors` allows any `Collection`s containing strings to be passed as arguments to this method

`.java`

Obtain `Collection` iterator

(3 of 3)

`Iterator` method `hasNext` determines whether the `Iterator` contains more elements

Line 56

`Iterator` method `next` returns a reference to the next element

Line 55

Collection method `contains` determines whether `collection2` contains the element returned by `next`

Use `Iterator` method `remove` to remove `String` from `Iterator`

Common Programming Error 19.2

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."

19.5.2 LinkedList

- `LinkedList` example
  - Add elements of one `List` to the other
  - Convert `String`s to uppercase
  - Delete a range of elements

Outline

ListTest.java

(1 of 4)

Lines 17-18

Line 22

```
1  // Fig. 19.4: ListTest.java
2  // Using LinkLists.
3  import java.util.List;
4  import java.util.LinkedList;
5  import java.util.ListIterator;
6
7  public class ListTest
8  {
9     private static final String colors[] = { "black", "yellow",
10       "green", "blue", "violet", "silver" };
11    private static final String colors2[] = { "gold", "white",
12       "brown", "blue", "gray", "silver" };
13
14    // set up and manipulate LinkedList objects
15    public ListTest()
16    {
17       List< String > list1 = new LinkedList< String >();
18       List< String > list2 = new LinkedList< String >();
19
20       // add elements to list link
21       for ( String color : colors )
22          list1.add( color );
23
```

Create two `LinkedList` objects

Use `List` method `add` to append elements from array `colors` to the end of `list1`

```
24       // add elements to list link2
25       for ( String color : colors2 )
26          list2.add( color );
27
28       list1.addAll( list2 ); // concatenate lists
29       list2 = null; // release resources
30       printList( list1 ); // print list1 elements
31
32       convertToUppercaseStrings( list1 ); // conve
33       printList( list1 ); // print list1 elements
34
35       System.out.print( "\nDeleting elements 4 to 6..." );
36       removeItems( list1, 4, 7 ); // remove items 4-7 from list
37       printList( list1 ); // print list1 elements
38       printReversedList( list1 ); // print list in reverse order
39    } // end ListTest constructor
40
41    // output List contents
42    public void printList( List< String > list )
43    {
44       System.out.println( "\nlist: " );
45
46       for ( String color : list )
47          System.out.printf( "%s ", color );
48
49       System.out.println();
50    } // end method printList
51
```

Use `List` method `add` to append elements from array `colors2` to the end of `list2`

Use `List` method `addAll` to append all elements of `list2` to the end of `list1`

Method `printList` allows any `List`s containing strings to be passed as arguments to this method

ListTest.java

Line 26

Line 28

Line 42

```
52    // locate String objects and convert to uppercase
53    private void convertToUppercaseStrings( List< String > list )
54    {
55       ListIterator< String > iterator = list.listIterator();
56
57       while ( iterator.hasNext() )
58       {
59          String color = iterator.next(); // get item
60          iterator.set( color.t
61       } // end while
62    } // end method convertToUp
63
64    // obtain sublist and use clear method t
65    private void removeItems( List< String >
66    {
67       list.subList( start, end ).clear(); // remove items
68    } // end method removeItems
69
70    // print reversed list
71    private void printReversedList( List
72    {
73       ListIterator< String > iterator = list.listIterator( list.size() );
74
```

Outline

Method `convertToUppercaseStrings`

Invoke `List` method `listIterator` to get a bidirectional iterator for the List

Invoke `ListIterator` method `hasN... Li...`

Invoke `ListIterator` method `next` to...

Line 53

Invoke `ListIterator` method `set` to replace the current `String` to which `iterator` refers with the `String` returned by method `toUpperCase`

Method `removeItems` allows any `List`s containing ... to this method

Invoke `List` method `subList` to obtain a portion of the `List`

Line 65

Method `printReversedList` allows any `List`s co... passed as argu...

...e 67

Invoke `List` method `listIterator` with one argument that specifies the starting position to get a bidirectional iterator for the list

```
75       System.out.println( "\nReversed List:" );
76
77       // print list in reverse order
78       while ( iterator.hasPrevious() )
79          System.out.printf( "%s ", iterator.previous() );
80    } // end method printReversedList
81
82    public static void main( String args[] )
83    {
84       new ListTest();
85    } // end main
86 } // end class ListTest
```

The `while` condition calls method `hasPrevious` to determine whether there are more elements while traversing the list backward

Invoke `ListIterator` method `previous` to get the previous element from the list

ListTest.java

(4 of 4)

Line 79

Program output

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

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

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

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

19.5.2 `Linkedlist` (Cont.)

- **`static` method `asList` of class `Arrays`**
  - View an array as a `List` collection
  - 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
  - Only operation permitted on the view returned by `asList` is *`set`*

Outline

UsingToArray.java

(1 of 2)

```
1  // Fig. 19.5: UsingToArray.java
2  // Using method toArray.
3  import java.util.LinkedList;
4  import java.util.Arrays;
5
6  public class UsingToArray
7  {
8     // constructor creates LinkedList, adds elements and converts to array
9     public UsingToArray()
10    {
11       String colors[] = { "black", "blue", "yellow" };
12
13       LinkedList< String > links =
14          new LinkedList< String >( Arrays.asList( colors ) );
15
16       links.addLast( "red" ); // add as last item
17       links.add( "pink" );    // add to the end
18       links.add( 3, "green" );  // add at 3rd index
19       links.addFirst( "cyan" ); // add as first item
20
```

Call method `asList` to create a `List` view of array `colors`, which is then used for creating a `LinkedList`

Call `LinkedList` method `addLast` to add "`red`" to the end of `links`

Call `LinkedList` method `add` to add "`pink`" as the last element and "`green`" as the element at index 3

Call `LinkedList` method `addFirst` to add "`cyan`" as the new first item in the `LinkedList`

```
21       // get LinkedList elements as an array
22       colors = links.toArray( new String[ links.size() ] );
23
24       System.out.println( "colors: " );
25
26       for ( String color : colors )
27          System.out.println( color );
28    } // end UsingToArray constructor
29
30    public static void main( String args[] )
31    {
32       new UsingToArray();
33    } // end main
34 } // end class UsingToArray
```

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

Use `List` method `toArray` to obtain array representation of `LinkedList`

Outline

ava

(2 of 2)

Line 22

Program output

Common Programming Error 19.3

Passing an array that contains data to `toArray` can cause logic errors. 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—without preserving the array argument'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.

19.5.3 Vector

- Class `Vector`
  - Array-like data structures that can resize themselves dynamically
  - Contains a *capacity*
  - Grows by *capacity increment* if it requires additional space

Performance Tip 19.2

Inserting an element into a `Vector` whose current size is less than its capacity is a relatively fast operation.

Performance Tip 19.3

Inserting an element into a `Vector` that needs to grow larger to accommodate the new element is a relatively slow operation.

Performance Tip 19.4

The default capacity increment doubles the size of the `Vector`. This may seem a waste of storage, but it is actually an efficient way for many `Vector`s to grow quickly to be "about the right size." This operation is much more efficient than growing the `Vector` each time by only as much space as it takes to hold a single element. The disadvantage is that the `Vector` might occupy more space than it requires. This is a classic example of the space–time trade-off.

Performance Tip 19.5

If storage is at a premium, use `Vector` method `trimToSize` to trim a `Vector`'s capacity to the `Vector`'s exact size. This operation optimizes a `Vector`'s use of storage. However, adding another element to the `Vector` will force the `Vector` to grow dynamically (again, a relatively slow operation)—trimming leaves no room for growth.

Outline

VectorTest.java

(1 of 4)

```
1  // Fig. 19.6: VectorTest.java
2  // Using the Vector class.
3  import java.util.Vector;
4  import java.util.NoSuchElementException;
5
6  public class VectorTest
7  {
8     private static final String colors[] = { "red", "white", "blue" };
9
10    public VectorTest()
11    {
12       Vector< String > vector = new Vector< String >();
13       printVector( vector ); // print vector
14
15       // add elements to the vector
16       for ( String color : colors )
17          vector.add( color );
18
19       printVector( vector ); // print
20
```

Create `Vector` of type `String` with initial capacity of 10 element and capacity increment of zero

Call `Vector` method `add` to add objects (`String`s in this example) to the end of the `Vector`

Outline

```
21      // output the first and last elements
22      try
23      {
24         System.out.printf( "First element: %s\n", vector.firstElement());
25         System.out.printf( "Last element: %s\n", vector.lastElement() );
26      } // end try
27      // catch exception if vector is empty
28      catch ( NoSuchElementException exception )
29      {
30         exception.printStackTrace()
31      } // end catch
32
33      // does vector contain "red"?
34      if ( vector.contains( "red" ) )
35         System.out.printf( "\n\"red\" found at
36            vector.indexOf( "red" ) );
37      else
38         System.out.println( "\n\"red\" n
39
40      vector.remove( "red" );// remove the string "red"
41      System.out.println( "\"red\" has been removed" );
42      printVector( vector ); // print vector
43
```

Call `Vector` method `firstElement` to return a reference to the first element in the `Vector`

Call `Vector` method `lastElement` to return a reference to the last element in the `Vector`

`Vector` method `contains` returns `boolean` that indicates whether `Vector` contains a specific `Object`

`Vector` method `remove` removes the first occurrence of its argument `Object` from `Vector`

`Vector` method `indexOf` returns index of first location in `Vector` containing the argument

Line 24

Line 35

Line 36

Line 40

Outline

VectorTest.java

(3 of 4)

```
44       // does vector contain "red" after remove operation?
45       if ( vector.contains( "red" ) )
46          System.out.printf(
47             "\"red\" found at index %d\n", vector.indexOf( "red" ) );
48       else
49          System.out.println( "\"red\" not found" );
50
51       // print the size and capacity of vector
52       System.out.printf( "\nSize: %d\nCapacity: %d\n", vector.size(),
53          vector.capacity() );
54    } // end Vector constructor
55
56    private void printVector( Vector< String > vectorToOutput )
57    {
58       if ( vectorToOutput.isEmpty() )
59          System.out.print( "vector is empty"
60       else  // iterate through the elements
61       {
62          System.out.print( "vector contains
63
64          // output elements
65          for ( String element : vectorToOutput )
66             System.out.printf( "%s ", element );
67       } // end else
68
```

`Vector` methods `size` and `capacity` return number of `elements` in `Vector` and `Vector` capacity, respectively

Method `printVector` allows any `Vector`s containing strings to be passed as arguments to this method

`Vector` method `isEmpty` returns true if there are no elements in the Vector

```
69       System.out.println( "\n" );
70    } // end method printVector
71
72    public static void main( String args[] )
73    {
74       new VectorTest(); // create object and call its constructor
75    } // end main
76 } // end class VectorTest
```

```
vector is empty

vector contains: red white blue

First element: red
Last element: blue

"red" found at index 0

"red" has been removed
vector contains: white blue

"red" not found

Size: 2
Capacity: 10
```

Outline

VectorTest.java

(4 of 4)

Program output

Common Programming Error 19.4

Without overriding method `equals`, the program performs comparisons using operator == to determine whether two references refer to the same object in memory.

Performance Tip 19.6

`Vector` methods `contains` and `indexOf` perform linear searches of a `Vector`'s contents. These searches are inefficient for large `Vectors`. If a program frequently searches for elements in a collection, consider using one of the Java Collection API's `Map` implementations (Section 19.10), which provide high-speed searching capabilities.

19.6 Collections Algorithms

- Collections framework provides set of algorithms
  - Implemented as `static` methods
    - `List` algorithms
      - `sort`
      - `binarySearch`
      - `reverse`
      - `shuffle`
      - `fill`
      - `copy`

- **`Collection` algorithms**
  - **`min`**
  - **`max`**
  - **`addAll`**
  - **`frequency`**
  - **`disjoint`**

Algorithm	Description
`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.
`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.

Fig. 19.7 | Collections algorithms.

Software Engineering Observation 19.4

The collections framework algorithms are polymorphic. That is, each algorithm can operate on objects that implement specific interfaces, regardless of the underlying implementations.

19.6.1 Algorithm `sort`

- `sort`
  - Sorts `List` elements
    - Order is determined by natural order of elements' type
    - `List` elements must implement the `Comparable` interface
    - Or, pass a `Comparator` to method `sort`
- Sorting in ascending order
  - Collections method `sort`
- Sorting in descending order
  - Collections static method `reverseOrder`
- Sorting with a `Comparator`
  - Create a custom `Comparator` class

Outline

Sort1.java

(1 of 2)

Line 15

```
1  // Fig. 19.8: Sort1.java
2  // Using algorithm sort.
3  import java.util.List;
4  import java.util.Arrays;
5  import java.util.Collections;
6
7  public class Sort1
8  {
9     private static final String suits[] =
10       { "Hearts", "Diamonds", "Clubs", "Spades" };
11
12    // display array elements
13    public void printElements()
14    {
15       List< String > list = Arrays.asList( suits ); // create
16
```

Create `List` of `String`s

```
17       // output list
18       System.out.printf( "Unsorted array elements:\n%s\n", list );
19
20       Collections.sort( list ); // sort ArrayList
21
22       // output list
23       System.out.printf( "Sorted array elements:\n%s\n", list );
24    } // end method printElements
25
26    public static void main( String args[] )
27    {
28       Sort1 sort1 = new Sort1();
29       sort1.printElements();
30    } // end main
31 } // end class Sort1
```

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

Implicit call to the `list`'s `toString` method to output the list contents

Use algorithm `sort` to order the elements of `list` in ascending order

Outline

(2 of 2)

18 and 23

Line 20

Program output

Outline

Sort2.java

(1 of 2)

```
1  // Fig. 19.9: Sort2.java
2  // Using a Comparator object with algorithm sort.
3  import java.util.List;
4  import java.util.Arrays;
5  import java.util.Collections;
6
7  public class Sort2
8  {
9     private static final String suits[] =
10       { "Hearts", "Diamonds", "Clubs", "Spades" };
11
12    // output List elements
13    public void printElements()
14    {
15       List list = Arrays.asList( suits ); // create List
16
```

Outline

Sort2.java

```
17       // output List elements
18       System.out.printf( "Unsorted array elements:\n%s\n", list );
19
20       // sort in descending order using a comparator
21       Collections.sort( list, Collections.reverseOrder() );
22
23       // output List elements
24       System.out.printf( "Sorted list elements:\n%s\
25    } // end method printElements
26
27    public static void main( String args[] )
28    {
29       Sort2 sort2 = new Sort2();
30       sort2.printElements();
31    } // end main
32 } // end class Sort2
```

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

Method `reverseOrder` of class `Collections` returns a `Comparator` object that represents the collection's reverse order

Method `sort` of class `Collections` can use a `Comparator` object to sort a `List`

Outline

```
1  // Fig. 19.10: TimeComparator.java
2  // Custom Comparator class that compares two Time2 objects.
3  import java.util.Comparator;
4
5  public class TimeComparator implements Comparator< Time2 >
6  {
7     public int compare( Time2 tim1, Time2 time2 )
8     {
9        int hourCompare = time1.getHour() - time2.getHour();
10
11       // test the hour first
12       if ( hourCompare != 0 )
13          return hourCompare;
14
15       int minuteCompare =
16          time1.getMinute() - time2.getMinute(); // compare minute
17
18       // then test the minute
19       if ( minuteCompare != 0 )
20          return minuteCompare;
21
22       int secondCompare =
23          time1.getSecond() - time2.getSecond(); // compare second
24
25       return secondCompare; // return result of comparing seconds
26    } // end method compare
27 } // end class TimeComparator
```

Custom comparator `TimeComparator` implements `Comparator` interface and compares `Time2` object

Implement method `compare` to determine the order of two `Time2` objects

Outline

Sort3.java

(1 of 2)

```
1  // Fig. 19.11: Sort3.java
2  // Sort a list using the custom Comparator class TimeComparator.
3  import java.util.List;
4  import java.util.ArrayList;
5  import java.util.Collections;
6
7  public class Sort3
8  {
9     public void printElements()
10    {
11       List< Time2 > list = new ArrayList< Time2 >(); // create List
12
13       list.add( new Time2(  6, 24, 34 ) );
14       list.add( new Time2( 18, 14, 58 ) );
15       list.add( new Time2(  6, 05, 34 ) );
16       list.add( new Time2( 12, 14, 58 ) );
17       list.add( new Time2(  6, 24, 22 ) );
18
```

Outline

Sort3.java

```
19       // output List elements
20       System.out.printf( "Unsorted array elements:\n%s\n", list );
21
22       // sort in order using a comparator
23       Collections.sort( list, new TimeComparator() );
24
25       // output List elements
26       System.out.printf( "Sorted list elements:\n%s\n",
27    } // end method printElements
28
29    public static void main( String args[] )
30    {
31       Sort3 sort3 = new Sort3();
32       sort3.printElements();
33    } // end main
34 } // end class Sort3
```

Sort in order using a custom comparator `TimeComparator`

Line 23

Program output

```
Unsorted array elements:
[6:24:34 AM, 6:14:58 PM, 6:05:34 AM, 12:14:58 PM, 6:24:22 AM]
Sorted list elements:
[6:05:34 AM, 6:24:22 AM, 6:24:34 AM, 12:14:58 PM, 6:14:58 PM]
```

19.6.2 Algorithm `shuffle`

- **`shuffle`**
  - Randomly orders `List` elements

Outline

DeckOfCards.java

(1 of 4)

```
1  // Fig. 19.12: DeckOfCards.java
2  // Using algorithm shuffle.
3  import java.util.List;
4  import java.util.Arrays;
5  import java.util.Collections;
6
7  // class to represent a Card in a deck of cards
8  class Card
9  {
10    public static enum Face { Ace, Deuce, Three, Four, Five, Six,
11       Seven, Eight, Nine, Ten, Jack, Queen, King  };
12    public static enum Suit { Clubs, Diamonds, Hearts, Spades };
13
14    private final Face face; // face of card
15    private final Suit suit; // suit of card
16
17    // two-argument constructor
18    public Card( Face cardFace, Suit cardSuit )
19    {
20        face = cardFace; // initialize face of card
21        suit = cardSuit; // initialize suit of card
22    } // end two-argument Card constructor
23
24    // return face of the card
25    public Face getFace()
26    {
27       return face;
28    } // end method getFace
29
```

Outline

DeckOfCards.java

(2 of 4)

```
30    // return suit of Card
31    public Suit getSuit()
32    {
33       return suit;
34    } // end method getSuit
35
36    // return String representation of Card
37    public String toString()
38    {
39       return String.format( "%s of %s", face, suit );
40    } // end method toString
41 } // end class Card
42
43 // class DeckOfCards declaration
44 public class DeckOfCards
45 {
46    private List< Card > list; // declare List that will store Cards
47
48    // set up deck of Cards and shuffle
49    public DeckOfCards()
50    {
51       Card[] deck = new Card[ 52 ];
52       int count = 0; // number of cards
53
```

Outline

```
54       // populate deck with Card objects
55       for ( Card.Suit suit : Card.Suit.values() )
56       {
57          for ( Card.Face face : Card.Face.value
58          {
59             deck[ count ] = new Card( face, sui
60             count++;
61          } // end for
62       } // end for
63
64       list = Arrays.asList( deck ); // get List
65       Collections.shuffle( list ); // shuffle deck
66    } // end DeckOfCards constructor
67
68    // output deck
69    public void printCards()
70    {
71       // display 52 cards in two columns
72       for ( int i = 0; i < list.size(); i++ )
73          System.out.printf( "%-20s%s", list.get( i ),
74             ( ( i + 1 ) % 2 == 0 ) ? "\n" : "\t" );
75    } // end method printCards
76
77    public static void main( String args[] )
78    {
79       DeckOfCards cards = new DeckOfCards();
80       cards.printCards();
81    } // end main
82 } // end class DeckOfCards
```

s.java

Use `enum` type `Suit` outside of class `Card`, qualify the `enum`'s type name (`Suit`) with the class name `Card` and a dot (`.`) separator

Use `enum` type `Face` outside of class `Card`, qualify the `enum`'s type name (`Face`) with the class name `Card` and a dot (`.`) separator

Invoke `static` method `asList` of class `Arrays` to get a `List` view of the `deck` array

Use method `shuffle` of class `Collections` to shuffle `List`

```
King of Diamonds    Jack of Spades
Four of Diamonds    Six of Clubs
King of Hearts      Nine of Diamonds
Three of Spades     Four of Spades
Four of Hearts      Seven of Spades
Five of Diamonds    Eight of Hearts
Queen of Diamonds   Five of Hearts
Seven of Diamonds   Seven of Hearts
Nine of Hearts      Three of Clubs
Ten of Spades       Deuce of Hearts
Three of Hearts     Ace of Spades
Six of Hearts       Eight of Diamonds
Six of Diamonds     Deuce of Clubs
Ace of Clubs        Ten of Diamonds
Eight of Clubs      Queen of Hearts
Jack of Clubs       Ten of Clubs
Seven of Clubs      Queen of Spades
Five of Clubs       Six of Spades
Nine of Spades      Nine of Clubs
King of Spades      Ace of Diamonds
Ten of Hearts       Ace of Hearts
Queen of Clubs      Deuce of Spades
Three of Diamonds   King of Clubs
Four of Clubs       Jack of Diamonds
Eight of Spades     Five of Spades
Jack of Hearts      Deuce of Diamonds
```

Outline

DeckOfCards.java

(4 of 4)

Program output

19.6.3 Algorithm `reverse`, `fill`, `copy`, `max` and `min`

- **`reverse`**
  - Reverses the order of `List` elements
- **`fill`**
  - Populates `List` elements with values
- **`copy`**
  - Creates copy of a `List`
- **`max`**
  - Returns largest element in `List`
- **`min`**
  - Returns smallest element in `List`

Outline

Algorithms1.java

(1 of 3)

Line 24

```
1  // Fig. 19.13: Algorithms1.java
2  // Using algorithms reverse, fill, copy, min and max.
3  import java.util.List;
4  import java.util.Arrays;
5  import java.util.Collections;
6
7  public class Algorithms1
8  {
9     private Character[] letters = { 'P', 'C', 'M' };
10    private Character[] lettersCopy;
11    private List< Character > list;
12    private List< Character > copyList;
13
14    // create a List and manipulate it with methods from Collections
15    public Algorithms1()
16    {
17       list = Arrays.asList( letters ); // get List
18       lettersCopy = new Character[ 3 ];
19       copyList = Arrays.asList( lettersCopy ); // list view of lettersCopy
20
21       System.out.println( "Initial list: " );
22       output( list );
23
24       Collections.reverse( list ); // reverse order
25       System.out.println( "\nAfter calling reverse: " );
26       output( list );
27
```

Use method `reverse` of class `Collections` to obtain `List` in reverse order

```
28       Collections.copy( copyList, list ); // copy List
29       System.out.println( "\nAfter copying: " );
30       output( copyList );
31
32       Collections.fill( list, 'R' ); // fill list with Rs
33       System.out.println( "\nAfter calling fill: " );
34       output( list );
35    } // end Algorithms1 constructor
36
37    // output List information
38    private void output( List< Character > listRef )
39    {
40       System.out.print( "The list is: " );
41
42       for ( Character element : listRef )
43          System.out.printf( "%s ", element );
44
45       System.out.printf( "\nMax: %s", Collections.max( listRef ) );
46       System.out.printf( "  Min: %s\n", Collections.min( listRef ) );
47    } // end method output
48
```

Use method `copy` of class `Collections` to obtain copy of `List`

Use method `fill` of class `Collections` to populate `List` with the letter `'R'`

Obtain maximum value in `List`

Obtain minimum value in `List`

Algorithms1.java

Line 32

Line 45

```
49    public static void main( String args[] )
50    {
51       new Algorithms1();
52    } // end main
53 } // end class Algorithms1
```

```
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
```

Outline

Algorithms1.java

(3 of 3)

Program output

19.6.4 Algorithm `binarySearch`

- **`binarySearch`**
  - Locates object in `List`
    - Returns index of object in `List` if object exists
    - Returns negative value if Object does not exist
      - Calculate insertion point
      - Make the insertion point sign negative
      - Subtract 1 from insertion point

Outline

BinarySearchTest.java

(1 of 3)

Line 18

```
1  // Fig. 19.14: BinarySearchTest.java
2  // Using algorithm binarySearch.
3  import java.util.List;
4  import java.util.Arrays;
5  import java.util.Collections;
6  import java.util.ArrayList;
7
8  public class BinarySearchTest
9  {
10    private static final String colors[] = { "red", "white",
11       "blue", "black", "yellow", "purple", "tan", "pink" };
12    private List< String > list; // ArrayList reference
13
14    // create, sort and output list
15    public BinarySearchTest()
16    {
17       list = new ArrayList< String >( Arrays.asList( colors ) );
18       Collections.sort( list ); // sort the ArrayList
19       System.out.printf( "Sorted ArrayList: %s\n", list );
20    } // end BinarySearchTest constructor
21
```

Sort `List` in ascending order

Outline

BinarySearchTest.java

(2 of 3)

Line 39

```
22    // search list for various values
23    private void search()
24    {
25       printSearchResults( colors[ 3 ] ); // first item
26       printSearchResults( colors[ 0 ] ); // middle item
27       printSearchResults( colors[ 7 ] ); // last item
28       printSearchResults( "aqua" ); // below lowest
29       printSearchResults( "gray" ); // does not exist
30       printSearchResults( "teal" ); // does not exist
31    } // end method search
32
33    // perform searches and display search result
34    private void printSearchResults( String key )
35    {
36       int result = 0;
37
38       System.out.printf( "\nSearching for: %s\n", key );
39       result = Collections.binarySearch( list, key );
40
41       if ( result >= 0 )
42          System.out.printf( "Found at index %d\n", result );
43       else
44          System.out.printf( "Not Found (%d)\n",result );
45    } // end method printSearchResults
46
```

Use method `binarySearch` of class `Collections` to search `list` for specified `key`

```
47    public static void main( String args[] )
48    {
49       BinarySearchTest binarySearchTest = new BinarySearchTest();
50       binarySearchTest.search();
51    } // end main
52 } // end class BinarySearchTest
```

```
Sorted ArrayList: [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)
```

Outline

BinarySearchTest.java

(3 of 3)

19.6.5 Algorithms addAll, frequency and disjoint

- addAll
  - Insert all elements of an array into a collection
- frequency
  - Calculate the number of times a specific element appear in the collection
- Disjoint
  - Determine whether two collections have elements in common

Outline

Algorithms2.java

(1 of 3)

```
1  // Fig. 19.15: Algorithms2.java
2  // Using algorithms addAll, frequency and disjoint.
3  import java.util.List;
4  import java.util.Vector;
5  import java.util.Arrays;
6  import java.util.Collections;
7
8  public class Algorithms2
9  {
10    private String[] colors = { "red", "white", "yellow", "blue" };
11    private List< String > list;
12    private Vector< String > vector = new Vector< String >();
13
14    // create List and Vector
15    // and manipulate them with methods from Collections
16    public Algorithms2()
17    {
18       // initialize list and vector
19       list = Arrays.asList( colors );
20       vector.add( "black" );
21       vector.add( "red" );
22       vector.add( "green" );
23
24       System.out.println( "Before addAll, vector contains: " );
25
```

```
26       // display elements in vector
27       for ( String s : vector )
28          System.out.printf( "%s ", s );
29
30       // add elements in colors to list
31       Collections.addAll( vector, colors );
32
33       System.out.println( "\n\nAfter addAll, vector
34
35       // display elements in vector
36       for ( String s : vector )
37          System.out.printf( "%s ", s );
38
39       // get frequency of "red"
40       int frequency = Collections.frequency( vector, "red" );
41       System.out.printf(
42          "\n\nFrequency of red in vector: %d\n", frequ
43
```

Invoke method `addAll` to add elements in array `colors` to `vector`

Get the frequency of `String` "`red`" in `Collection` `vector` using method `frequency`

Outline

`Algorithms2.java`

(2 of 3)

Line 31

Line 40

```
44       // check whether list and vector have elements in common
45       boolean disjoint = Collections.disjoint( list, vector );
46
47       System.out.printf( "\nlist and vector %s elements
48          ( disjoint ? "do not have" : "have"  ) );
49    } // end Algorithms2 constructor
50
51    public static void main( String args[] )
52    {
53       new Algorithms2();
54    } // end main
55 } // end class Algorithms2
```

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

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

Frequency of red in vector: 2

list and vector have elements in common
```

Invoke method `disjoint` to test whether `Collections` `list` and `vector` have elements in common

Outline

java

(3 of 3)

Line 45

19.7 Stack Class of Package java.util

- Stack
  - Implements stack data structure
  - Extends class Vector
  - Stores references to objects

Outline

StackTest.java

(1 of 4)

```
1  // Fig. 19.16: StackTest.java
2  // Program to test java.util.Stack.
3  import java.util.Stack;
4  import java.util.EmptyStackException;
5
6  public class StackTest
7  {
8     public StackTest()
9     {
10       Stack< Number > stack = new Stack< Number >();
11
12       // create numbers to store in the stack
13       Long longNumber = 12L;
14       Integer intNumber = 34567;
15       Float floatNumber = 1.0F;
16       Double doubleNumber = 1234.5678;
17
18       // use push method
19       stack.push( longNumber ); // push a long
20       printStack( stack );
21       stack.push( intNumber ); // push an int
22       printStack( stack );
23       stack.push( floatNumber ); // push a float
24       printStack( stack );
25       stack.push( doubleNumber ); // push a double
26       printStack( stack );
27
```

Create an empty `Stack` of type `Number`

`Stack` method `push` adds object to top of `Stack`

Lines 19, 21, 23, 25

```
28       // remove items from stack
29       try
30       {
31          Number removedObject = null;
32
33          // pop elements from stack
34          while ( true )
35          {
36             removedObject = stack.pop(); // use pop method
37             System.out.printf( "%s popped\n", removedObject );
38             printStack( stack );
39          } // end while
40       } // end try
41       catch ( EmptyStackException emptyStackException )
42       {
43          emptyStackException.printStackTrace();
44       } // end catch
45    } // end StackTest constructor
46
47    private void printStack( Stack< Number > stack )
48    {
49       if ( stack.isEmpty() )
50          System.out.print( "stack is empty\n\n" ); // the stack is empty
51       else  // stack is not empty
52       {
53          System.out.print( "stack contains: " );
54
```

Stack method pop removes element from top of Stack

Stack method isEmpty returns true if Stack is empty

Outline

StackTest.java

(2 of 4)

Line 36

Line 49

```
55          // iterate through the elements
56          for ( Number number : stack )
57             System.out.printf( "%s ", number );
58
59          System.out.print( "(top) \n\n" ); // indicates top of the stack
60       } // end else
61    } // end method printStack
62
63    public static void main( String args[] )
64    {
65       new StackTest();
66    } // end main
67 } // end class StackTest
```

Outline

StackTest.java

(3 of 4)

```
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)

34567 popped
stack contains: 12 (top)

12 popped
stack is empty

java.util.EmptyStackException
        at java.util.Stack.peek(Unknown Source)
        at java.util.Stack.pop(Unknown Source)
        at StackTest.<init>(StackTest.java:36)
        at StackTest.main(StackTest.java:65)
```

Outline

StackTest.java

(4 of 4)

Program output

Error-Prevention Tip 19.1

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.

19.8 Class `PriorityQueue` and Interface `Queue`

- Interface **`Queue`**
  - New collection interface introduced in J2SE 5.0
  - Extends interface **`Collection`**
  - Provides additional operations for inserting, removing and inspecting elements in a queue
- Class **`PriorityQueue`**
  - Implements the **`Queue`** interface
  - Orders elements by their natural ordering
    - Specified by **`Comparable`** elements' **`compareTo`** method
    - **`Comparator`** object supplied through constructor

Outline

PriorityQueueTest.java

Line 10

Lines 13-15

Line 23

Program output

```
1  // Fig. 19.17: PriorityQueueTest.java
2  // Standard library class PriorityQueue test program.
3  import java.util.PriorityQueue;
4
5  public class PriorityQueueTest
6  {
7     public static void main( String args[] )
8     {
9        // queue of capacity 11
10       PriorityQueue< Double > queue = new PriorityQueue< Double >();
11
12       // insert elements to queue
13       queue.offer( 3.2 );
14       queue.offer( 9.8 );
15       queue.offer( 5.4 );
16
17       System.out.print( "Polling fro
18
19       // display elements in queue
20       while ( queue.size() > 0 )
21       {
22          System.out.printf( "%.1f ", queue.peek() ); //
23          queue.poll(); // remove top element
24       } // end while
25    } // end main
26 } // end class PriorityQueueTe
```

Create a `PriorityQueue` that stores `Double`s with an initial capacity of 11 elements and orders the objects's natural ordering

Use method `offer` to add elements to the priority queue

Use method `size` to determine whether the priority queue is empty

Use method `peek` to retrieve the highest-priority element in the queue

Use method `pool` to remove the highest-priority element from the queue

```
Polling from queue: 3.2 5.4 9.8
```

19.9 Sets

- **`Set`**
  - **`Collection` that contains unique elements**
  - **`HashSet`**
    - **Stores elements in hash table**
  - **`TreeSet`**
    - **Stores elements in tree**

Outline

SetTest.java

(1 of 2)

Line 18

```
1  // Fig. 19.18: SetTest.java
2  // Using a HashSet to remove duplicates.
3  import java.util.List;
4  import java.util.Arrays;
5  import java.util.HashSet;
6  import java.util.Set;
7  import java.util.Collection;
8
9  public class SetTest
10 {
11    private static final String colors[] = { "red", "white", "blue",
12       "green", "gray", "orange", "tan", "white", "cyan",
13       "peach", "gray", "orange" };
14
15    // create and output ArrayList
16    public SetTest()
17    {
18       List< String > list = Arrays.asList( colors );
19       System.out.printf( "ArrayList: %s\n", list );
20       printNonDuplicates( list );
21    } // end SetTest constructor
22
```

Create a `List` that contains `String` objects

```
23    // create set from array to eliminate duplicates
24    private void printNonDuplicates( Collection< String > collection )
25    {
26       // create a HashSet
27       Set< String > set = new HashSet< String >( col
28
29       System.out.println( "\nNonduplicates are: " );
30
31       for ( String s : set )
32          System.out.printf( "%s ", s );
33
34       System.out.println();
35    } // end method printNonDuplicates
36
37    public static void main( String args[] )
38    {
39       new SetTest();
40    } // end main
41 } // end class SetTest
```

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

Nonduplicates are:
red cyan white tan gray green orange blue peach
```

Outline

Method `printNonDuplicates` accepts a `Collection` of type `String`

Construct a `HashSet` from the `Collection` argument

(2 of 2)

Line 24

Line 27

Program output

Outline

SortedSetTest.java

(1 of 3)

Lines 16-17

```
1  // Fig. 19.19: SortedSetTest.java
2  // Using TreeSet and SortedSet.
3  import java.util.Arrays;
4  import java.util.SortedSet;
5  import java.util.TreeSet;
6
7  public class SortedSetTest
8  {
9     private static final String names[] = { "yellow", "green",
10       "black", "tan", "grey", "white", "orange", "red", "green" };
11
12    // create a sorted set with TreeSet, then manipulate it
13    public SortedSetTest()
14    {
15       // create TreeSet
16       SortedSet< String > tree =
17          new TreeSet< String >( Arrays.asList( names ) );
18
19       System.out.println( "sorted set: " );
20       printSet( tree ); // output contents of tree
21
```

Create `TreeSet` from `names` array

```
22       // get headSet based on "orange"
23       System.out.print( "\nheadSet (\"orange\"):  " );
24       printSet( tree.headSet( "orange" ) );
25
26       // get tailSet based upon "orange"
27       System.out.print( "tailSet (\"orange\"):  " );
28       printSet( tree.tailSet( "orange" ) );
29
30       // get first and last elements
31       System.out.printf( "first: %s\n", tree.first() );
32       System.out.printf( "last : %s\n", tree.last() );
33    } // end SortedSetTest constructor
34
35    // output set
36    private void printSet( SortedSet< String > set )
37    {
38       for ( String s : set )
39          System.out.printf( "%s ",  s );
40
```

Use `TreeSet` method `headSet` to get `TreeSet` subset less than `"orange"`

Use `TreeSet` method `tailSet` to get `TreeSet` subset greater than `"orange"`

Methods `first` and `last` obtain smallest and largest `TreeSet` elements, respectively

Line 28

Line 31

Line 32

```
41       System.out.println();
42    } // end method printSet
43
44    public static void main( String args[] )
45    {
46       new SortedSetTest();
47    } // end main
48 } // end class SortedSetTest
```

```
sorted set:
black green grey orange red tan white yellow

headSet ("orange"):  black green grey
tailSet ("orange"):  orange red tan white yellow
first: black
last : yellow
```

Outline

SortedSetTest.java

(3 of 3)

Program output

19.10 Maps

- **`Map`**
  - Associates keys to values
  - Cannot contain duplicate keys
    - Called *one-to-one mapping*
  - Implementation classes
    - **`Hashtable`**, **`HashMap`**
      - Store elements in hash tables
    - **`TreeMap`**
      - Store elements in trees
  - Interface **`SortedMap`**
    - Extends **`Map`**
    - Maintains its keys in sorted order

19.10 Maps (Cont.)

- `Map` implementation with hash tables
  - Hash tables
    - Data structure that use *hashing*
      - Algorithm for determining a *key* in table
        - Keys in tables have associated values (data)
    - Each table cell is a hash "bucket"
      - Linked list of all *key-value pairs* that hash to that cell
      - Minimizes *collisions*

Performance Tip 19.7

The load factor in a hash table is a classic example of a memory-space/execution-time trade-off: By increasing the load factor, we get better memory utilization, but the program runs slower, due to increased hashing collisions. By decreasing the load factor, we get better program speed, because of reduced hashing collisions, but we get poorer memory utilization, because a larger portion of the hash table remains empty.

Outline

WordTypeCount.java

(1 of 4)

Line 17

```
1  // Fig. 19.20: WordTypeCount.java
2  // Program counts the number of occurrences of each word in a string
3  import java.util.StringTokenizer;
4  import java.util.Map;
5  import java.util.HashMap;
6  import java.util.Set;
7  import java.util.TreeSet;
8  import java.util.Scanner;
9
10 public class WordTypeCount
11 {
12    private Map< String, Integer > map;
13    private Scanner scanner;
14
15    public WordTypeCount()
16    {
17       map = new HashMap< String, Integer >(); // create HashMap
18       scanner = new Scanner( System.in ); // create scanner
19       createMap(); // create map based on user input
20       displayMap(); // display map content
21    } // end WordTypeCount constructor
22
```

Create an empty `HashMap` with a default capacity 16 and a default load factor 0.75. The keys are of type `String` and the values are of type `Integer`

```
23   // create map from user input
24   private void createMap()
25   {
26      System.out.println( "Enter a string:" ); // prompt for user input
27      String input
28
29      // create S
30      StringTokenizer toke
31
32      // processi
33      while ( toke
34      {
35         String word = tokenizer.nextToken().toLowerCase(); // get word
36
37         // if the map contains the word
38         if ( map.containsKey( word ) ) // is word in map
39         {
40            int count = map.get( word ); // ge
41            map.put( word, count + 1 ); // inc
42         } // end if
43         else
44            map.put( word, 1 ); // add ne
45       } // end while
46   } // end method createMap
47
```

Create a `StringTokenizer` to break the input string argument into its component individual words

Use `StringTokenizer` method `hasMoreTokens` to determine whether there are more tokens in the string

Use `StringTokenizer` method `nextToken` to obtain the next token

Map method `containsKey` determines whether the key specified as an argument is in the hash table

Use method `get` to obtain the key's

Increment the value and use method `put` to replace the key's associated value

Create a new entry in the map, with the word as the key and an `Integer` object containing 1 as the value

WordTypeCount.java

(2 of 4)

Line 30

Line 33

Line 35

Line 44

```
48    // display map content
49    private void displayMap()
50    {
51       Set< String > keys = map.keySet(); // get
52
53       // sort keys
54       TreeSet< String > sortedKeys = new TreeSet< String >( keys );
55
56       System.out.println( "Map contains:\nK
57
58       // generate output fo
59       for ( String key : so
60          System.out.printf( "%-10s%10s\n", key, map.get( key ) );
61
62       System.out.printf(
63          "\nsize:%d\nisEmpty:%b\n", map.size(), map.isEmpty() );
64    } // end method displayMap
65
```

Use `HashMap` method `keySet` to obtain a set of the keys

Access each key and its value in the map

Call `Map` method `size` to get the number of key-value pairs in the `Map`

Call `Map` method `isEmpty` to determine whether the `Map` is empty

Outline

WordTypeCount.java

(3 of 4)

Line 51

Lines 59-60

Line 63

Line 63

```
66    public static void main( String args[] )
67    {
68       new WordTypeCount();
69    } // end main
70 } // end class WordTypeCount
```

```
Enter a string:
To be or not to be: that is the question Whether 'tis nobler to suffer
Map contains:
Key                  Value
'tis                    1
be                      1
be:                     1
is                      1
nobler                  1
not                     1
or                      1
question                1
suffer                  1
that                    1
the                     1
to                      3
whether                 1

size:13
isEmpty:false
```

Outline

WordTypeCount.java

(4 of 4)

Program output

19.11 Properties Class

- **Properties**
  - Persistent **Hashtable**
    - Can be written to output stream
    - Can be read from input stream
  - Provides methods **setProperty** and **getProperty**
    - Store/obtain key-value pairs of **String**s
- **Preferences API**
  - Replace Properties
  - More robust mechanism

Outline

PropertiesTest.java

(1 of 5)

Line 16

Lines 19-20

```
1  // Fig. 19.21: PropertiesTest.java
2  // Demonstrates class Properties of the java.util package.
3  import java.io.FileOutputStream;
4  import java.io.FileInputStream;
5  import java.io.IOException;
6  import java.util.Properties;
7  import java.util.Set;
8
9  public class PropertiesTest
10 {
11    private Properties table;
12
13    // set up GUI to test Properties table
14    public PropertiesTest()
15    {
16       table = new Properties(); // create Properties table
17
18       // set properties
19       table.setProperty( "color", "blue" );
20       table.setProperty( "width", "200" );
21
22       System.out.println( "After setting properties" );
23       listProperties(); // display property values
24
25       // replace property value
26       table.setProperty( "color", "red" );
27
```

Create empty `Properties`

`Properties` method `setProperty` stores value for the specified key

```
28      System.out.println( "After replacing properties" );
29      listProperties(); // display property values
30
31      saveProperties(); // save properties
32
33      table.clear(); // empty table
34
35      System.out.println( "After clearing properties" );
36      listProperties(); // display property values
37
38      loadProperties(); // load properties
39
40      // get value of property color
41      Object value = table.getProperty( "color" );
42
43      // check if value is in table
44      if ( value != null )
45         System.out.printf( "Property color's value is %s\n", value );
46      else
47         System.out.println( "Property color is not in table" );
48   } // end PropertiesTest constructor
49
```

Use `Properties` method `clear` to empty the hash table

Use `Properties` method `getProperty` to locate the value associated with the specified key

Outline

PropertiesTest.java

(2 of 5)

Line 33

```
50    // save properties to a file
51    public void saveProperties()
52    {
53       // save contents of table
54       try
55       {
56          FileOutputStream output = new FileOutputStream( "props.dat" );
57          table.store( output, "Sample Properties" ); // save properties
58          output.close();
59          System.out.println( "After saving
60          listProperties();
61       } // end try
62       catch ( IOException ioException )
63       {
64          ioException.printStackTrace();
65       } // end catch
66    } // end method saveProperties
67
```

`Properties` method `store` saves `Properties` contents to `FileOutputStream`

Outline

PropertiesTest.java

(3 of 5)

Line 57

Outline

PropertiesTest.java

(of 5)

Line 75

Line 89

Line 95

```
68    // load properties from a file
69    public void loadProperties()
70    {
71       // load contents of table
72       try
73       {
74          FileInputStream input = new FileInputStream( "props.dat" );
75          table.load( input ); // load properties
76          input.close();
77          System.out.println( "After loading proper
78          listProperties(); // display property val
79       } // end try
80       catch ( IOException ioException )
81       {
82          ioException.printStackTrace();
83       } // end catch
84    } // end method loadProperties
85
86    // output property values
87    public void listProperties()
88    {
89       Set< Object > keys = table.keySet(); // get
90
91       // output name/value pairs
92       for ( Object key : keys )
93       {
94          System.out.printf(
95             "%s\t%s\n", key, table.getProperty( ( String ) key ) );
96       } // end for
97
```

`Properties` method `load` restores `Properties` contents from `FileInputStream`

Use `Properties` method `keySet` to obtain a `Set` of the property names

Obtain the value of a property by passing a key to method `getProperty`

```
98       System.out.println();
99    } // end method listProperties
100
101   public static void main( String args[] )
102   {
103      new PropertiesTest();
104   } // end main
105} // end class PropertiesTest
```

```
After setting properties
color   blue
width   200

After replacing properties
color   red
width   200

After saving properties
color   red
width   200

After clearing properties

After loading properties
color   red
width   200

Property color's value is red
```

Outline

PropertiesTest.java

(5 of 5)

Program output

19.12 Synchronized Collections

- **Built-in collections are unsynchronized**
  - **Concurrent access to a `Collection` can cause errors**
  - **Java provides *synchronization wrappers* to avoid this**
    - **Via set of `public static` methods**

public static method headers

```
< T > Collection< T > synchronizedCollection( Collection< T > c )
< T > List< T > synchronizedList( List< T > aList )
< T > Set< T > synchronizedSet( Set< T > s )
< T > SortedSet< T > synchronizedSortedSet( SortedSet< T > s )
< K, V > Map< K, V > synchronizedMap( Map< K, V > m )
< K, V > SortedMap< K, V > synchronizedSortedMap( SortedMap< K, V > m )
```

Fig. 19.22 | Synchronization wrapper methods.

19.13 Unmodifiable Collections

- **Unmodifiable wrapper**
  - **Converting collections to unmodifiable collections**
  - **Throw `UnsorrtedOperationException` if attempts are made to modify the collection**

Software Engineering Observation 19.5

You can use an unmodifiable wrapper to create a collection that offers read-only access to others, while allowing read–write access to yourself. You do this simply by giving others a reference to the unmodifiable wrapper while retaining for yourself a reference to the original collection.

public static method headers
`< T > Collection< T > unmodifiableCollection( Collection< T > c )`
`< T > List< T > unmodifiableList( List< T > aList )`
`< T > Set< T > unmodifiableSet( Set< T > s )`
`< T > SortedSet< T > unmodifiableSortedSet( SortedSet< T > s )`
`< K, V > Map< K, V > unmodifiableMap( Map< K, V > m )`
`< K, V > SortedMap< K, V > unmodifiableSortedMap( SortedMap< K, V > m )`

Fig. 19.23 | Unmodifiable wrapper methods.

19.14 Abstract Implementations

- **Abstract implementations**
  - **Offer "bare bones" implementation of collection interfaces**
    - **Programmers can "flesh out" customizable implementations**
  - **`AbstractCollection`**
  - **`AbstractList`**
  - **`AbstractMap`**
  - **`AbstractSequentialList`**
  - **`AbstractSet`**
  - **`AbstractQueue`**