Week 12

Java Collections Framework

(Chapter 15)

Chapter Goals

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- To learn how to use the collection classes supplied in the Java library
- To use iterators to traverse collections
- To choose appropriate collections for solving programming problems
- To study applications of stacks and queues

An Overview of the Collections Framework

- A collection groups together elements and allows them to be retrieved later.
- Java collections framework: a hierarchy of interface types and classes for collecting objects.
  - Each interface type is implemented by one or more classes

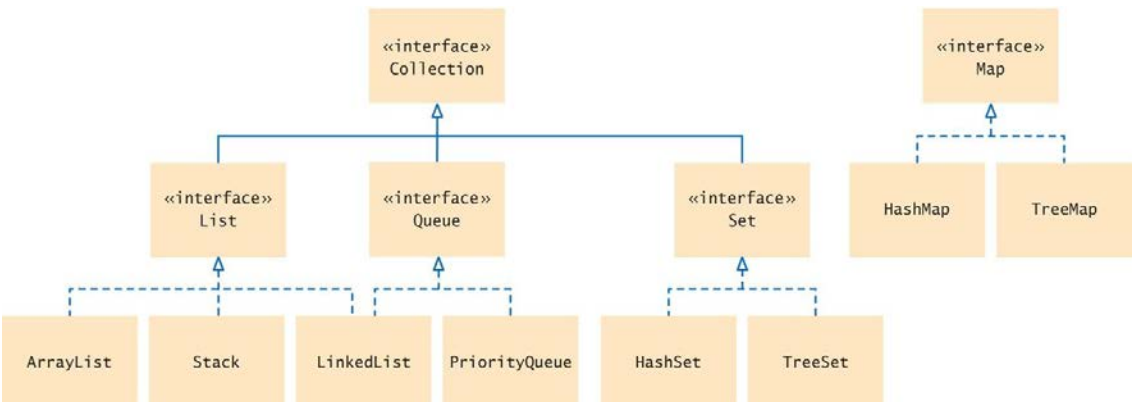

Figure 1 Interfaces and Classes in the Java Collections Framework

- The `Collection` interface is at the root
  - All `Collection` class implement this interface
  - So all have a common set of methods

An Overview of the Collections Framework

- `List` interface
- A list is a collection that remembers the order of its elements.
- Two implementing classes
  - `ArrayList`
  - `LinkedList`

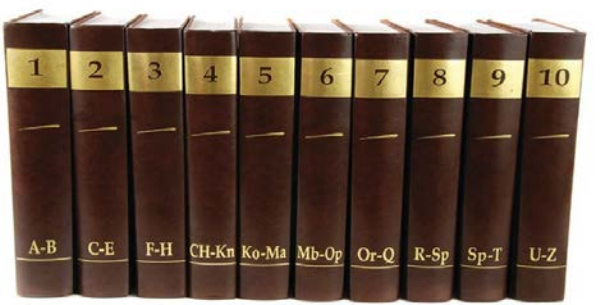

Figure 2 A List of Books

An Overview of the Collections Framework

- `Set` interface
- A set is an **unordered** collection of **unique** elements.
- Arranges its elements so that finding, adding, and removing elements is more efficient.
- Two mechanisms to do this
  - hash tables
  - binary search trees

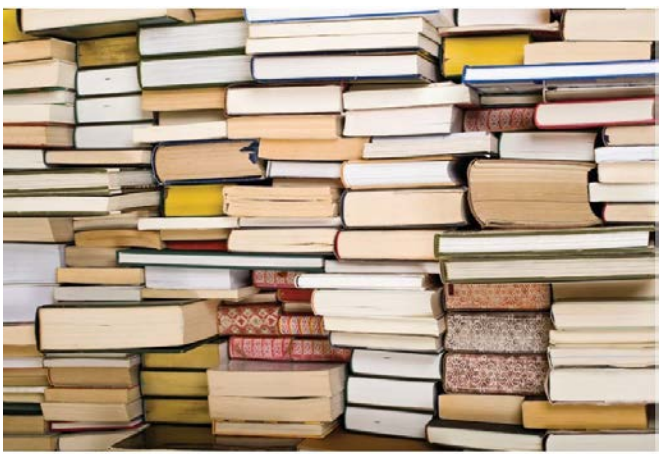

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Figure 3 A Set of Books

An Overview of the Collections Framework

- Stack
  - Remembers the order of elements
  - But you can only add and remove at the top

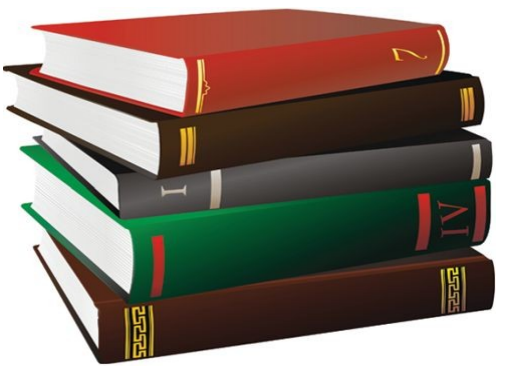

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Figure 4 A Stack of Books

An Overview of the Collections Framework

- Queue
  - Add items to one end (the tail) and remove them from the other end (the head)
- A queue of people

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- A priority queue
  - an unordered collection
  - has an efficient operation for removing the element with the highest priority

An Overview of the Collections Framework

- Map
  - Keeps associations between key and value objects.
  - Every key in the map has an associated value.
  - The map stores the keys, values, and the associations between them.

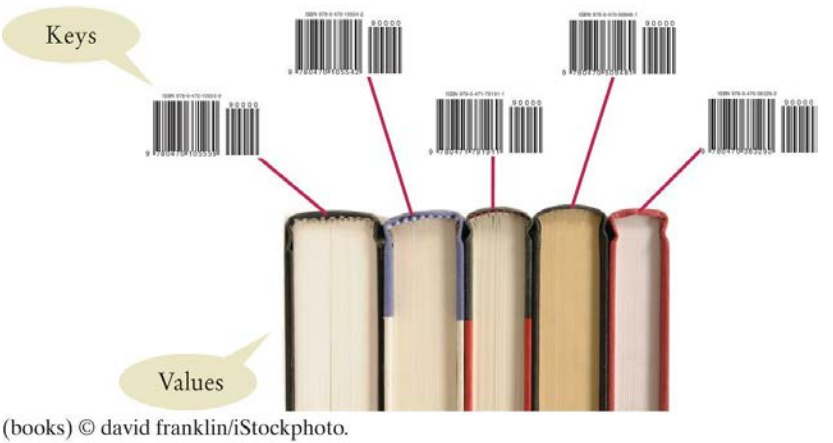

Figure 5 A Map from Bar Codes to Books

An Overview of the Collections Framework

- Every class that implements the `Collection` interface has these methods.

Table 1 The Methods of the `Collection` Interface

`Collection<String> coll = new ArrayList<>();`	The `ArrayList` class implements the `Collection` interface.
`coll = new TreeSet<>();`	The `TreeSet` class (Section 15.3) also implements the `Collection` interface.
`int n = coll.size();`	Gets the size of the collection. `n` is now `0`.
`coll.add("Harry");` `coll.add("Sally");`	Adds elements to the collection.
`String s = coll.toString();`	Returns a string with all elements in the collection. `s` is now `[Harry, Sally]`.
`System.out.println(coll);`	Invokes the `toString` method and prints `[Harry, Sally]`.
`coll.remove("Harry");` `boolean b = coll.remove("Tom");`	Removes an element from the collection, returning `false` if the element is not present. `b` is false.
`b = coll.contains("Sally");`	Checks whether this collection contains a given element. `b` is now `true`.

`for (String s : coll)`
`{`
`  System.out.println(s);`
`}`
	You can use the "for each" loop with any collection. This loop prints the elements on separate lines.

`Iterator<String> iter = coll.iterator();`	You use an iterator for visiting the elements in the collection (see Section 15.2.3).

The Diamond Syntax

- Convenient syntax enhancement for array lists and other generic classes.

- You can write:

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

instead of:

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

- This shortcut is called the "diamond syntax" because the empty brackets <> look like a diamond shape.
- This chapter, and the following chapters, will use the diamond syntax for generic classes.

Linked Lists

- A data structure used for collecting a sequence of objects:
  - Allows *efficient* addition and removal of elements in the middle of the sequence.
- A linked list consists of a number of nodes;
  - Each node has a reference to the next node.
- A node is an object that stores an element and references to the neighboring nodes.
- Each node in a linked list is connected to the neighboring nodes.

Linked Lists

- Adding and removing elements in the middle of a linked list is efficient.
- Visiting the elements of a linked list in sequential order is efficient.
- Random access is **not** efficient.

Figure 6 Example of a linked list

Linked Lists

- When inserting or removing a node:
  - Only the neighboring node references need to be updated

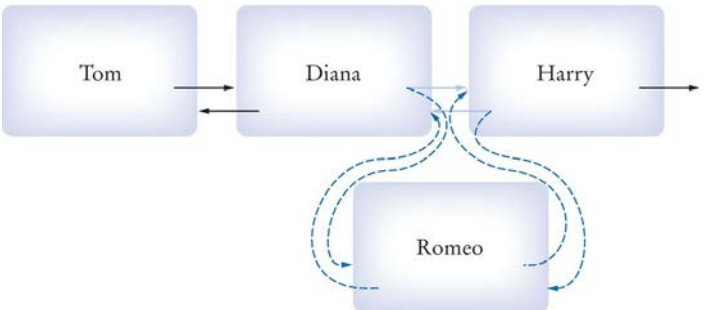

Figure 7 Inserting a Node into a Linked List

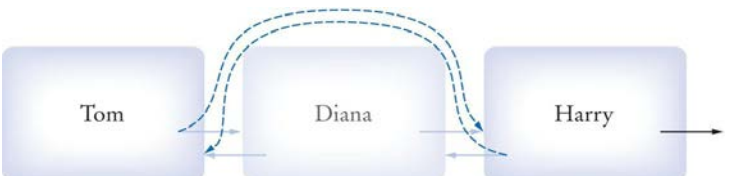

Figure 8 Removing a Node From A Linked List

- Visiting the elements of a linked list in sequential order is efficient.
- Random access is not efficient.

Linked Lists

- When to use a linked list:
  - You are concerned about the efficiency of inserting or removing elements
  - You rarely need element access in random order

The `LinkedList` Class of the Java Collections Framework

- Generic class
  - Specify type of elements in angle brackets: `LinkedList<Product>`
- Package: `java.util`
- `LinkedList` has the methods of the `Collection` interface.
- Some additional `LinkedList` methods:

Table 2 Working with Linked Lists

`LinkedList<String> list = new LinkedList<>();`	An empty list.
`list.addLast("Harry");`	Adds an element to the end of the list. Same as `add`.
`list.addFirst("Sally");`	Adds an element to the beginning of the list. `list` is now `[Sally, Harry]`.
`list.getFirst();`	Gets the element stored at the beginning of the list; here `"Sally"`.
`list.getLast();`	Gets the element stored at the end of the list; here `"Harry"`.
`String removed = list.removeFirst();`	Removes the first element of the list and returns it. `removed` is `"Sally"` and `list` is `[Harry]`. Use `removeLast` to remove the last element.
`ListIterator<String> iter = list.listIterator()`	Provides an iterator for visiting all list elements (see Table 3 on page 684).

List Iterator

- Use a list iterator to access elements inside a linked list.
- Encapsulates a position anywhere inside the linked list.
- Think of an iterator as pointing between two elements:
  - Analogy: like the cursor in a word processor points between two characters
- To get a list iterator, use the `listIterator` method of the `LinkedList` class.

```
LinkedList<String> employeeNames = . . .;
ListIterator<String> iterator =
employeeNames.listIterator();
```

- Also a generic type.

List Iterator

- Initially points before the first element.
- Move the position with `next` method:

```
if (iterator.hasNext())
{
  iterator.next();
}
```

- The `next` method returns the element that the iterator is passing.
- The return type of the `next` method matches the list iterator's type parameter.

List Iterator

- To traverse all elements in a linked list of strings:

```
while (iterator.hasNext())
{
   String name = iterator.next();
   Do something with name
}
```

- To use the “for each” loop:

```
for (String name : employeeNames)
{
   Do something with name
}
```

List Iterator

- The nodes of the `LinkedList` class store two links:
  - One to the next element
  - One to the previous one
  - Called a doubly-linked list
- To move the list position backwards, use:
  - `hasPrevious`
  - `previous`

Sample Program

- `ListDemo` is a sample program that:
  - Inserts strings into a list
  - Iterates through the list, adding and removing elements
  - Prints the list

section_2/ListDemo.java

```
1  import java.util.LinkedList;
2  import java.util.ListIterator;
3
4  /**
5     This program demonstrates the LinkedList class.
6  */
7  public class ListDemo
8  {
9     public static void main(String[] args)
10     LinkedList<String> staff = new LinkedList<>();
11          staff.addLast("Diana");
12          staff.addLast("Harry");
13          staff.addLast("Romeo");
14          staff.addLast("Tom");
15          // | in the comments indicates the iterator position
16          ListIterator<String> iterator = staff.listIterator(); // |DHRT
17          iterator.next(); // D|HRT
17          iterator.next(); // DH|RT
19          // Add more elements after second element
20          iterator.add("Juliet"); // DHJ|RT
21          iterator.add("Nina"); // DHJN|RT
22          iterator.next(); // DHJNR|T
23          // Remove last traversed element
24          iterator.remove(); // DHJN|
25          // Print all elements
26          System.out.println(staff);
27          System.out.println("Expected: [Diana, Harry, Juliet, Nina, Tom]");
```

Program Run:

```
[Diana Harry Juliet Nina Tom]
Expected: [Diana Harry Juliet Nina Tom]
```

A List Iterator

- The `add` method adds an object after the iterator.

  Then moves the iterator position past the new element.

```
iterator.add("Juliet");
```

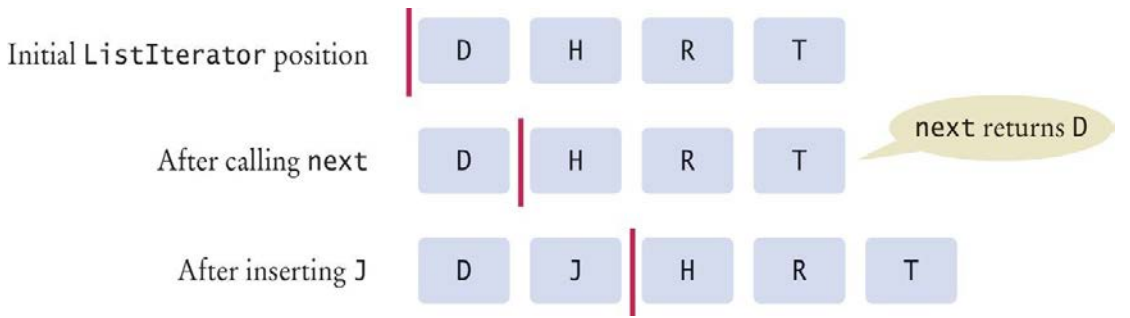

Figure 9 A Conceptual View of the List Iterator

List Iterator

- The `remove` method:

  Removes object that was returned by the last call to `next` or `previous`

- To remove all names that fulfill a certain condition:

```
while (iterator.hasNext())
{
   String name = iterator.next();
   if (condition is fulfilled for name)
      iterator.remove();
}
```

- Be careful when calling `remove`:

  It can be called only **once** after calling `next` or `previous`

  You cannot call it immediately after a call to `add`

  If you call it improperly, it throws an `IllegalStateException`

List Iterator

- `ListIterator` interface extends `Iterator` interface.
- Methods of the `Iterator` and `ListIterator` Interfaces

Table 3 Methods of the Iterator and ListIterator Interfaces

`String s = iter.next();`	Assume that `iter` points to the beginning of the list `[Sally]` before calling `next`. After the call, `s` is `"Sally"` and the iterator points to the end.
`iter.previous();` `iter.set("Juliet");`	The `set` method updates the last element returned by `next` or `previous`. The list is now `[Juliet]`.
`iter.hasNext()`	Returns `false` because the iterator is at the end of the collection.

`if (iter.hasPrevious())`
`{`
`  s = iter.previous();`
`}`
	`hasPrevious` returns `true` because the iterator is not at the beginning of the list. `previous` and `hasPrevious` are `ListIterator` methods.

`iter.add("Diana");`	Adds an element before the iterator position (`ListIterator` only). The list is now `[Diana, Juliet]`.
`iter.next();` `iter.remove();`	`remove` removes the last element returned by `next` or `previous`. The list is now `[Diana]`.

Sets

- A set organizes its values in an order that is optimized for efficiency.
- May not be the order in which you add elements.
- Inserting and removing elements is more efficient with a set than with a list.

Sets

- The `Set` interface has the same methods as the `Collection` interface.
- A set does not admit duplicates.
- Two implementing classes

  `HashSet` based on hash table

  `TreeSet` based on binary search tree
- A Set implementation arranges the elements so that it can locate them quickly.

Sets

- In a hash table

  Set elements are grouped into smaller collections of elements that share the same characteristic.

  Grouped by an integer hash code that is computed from the element.

- Elements in a hash table must implement the method `hashCode`.
- Must have a properly defined `equals` method.
- You can form hash sets holding objects of type `String`, `Integer`, `Double`, `Point`, `Rectangle`, or `Color`.

  `HashSet<String>`, `HashSet<Rectangle>`, or a `HashSet<HashSet<Integer>>`

- On this shelf, books of the same color are grouped together. Similarly, in a hash table, objects with the same hash code are placed in the same group.

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Sets

- In a `TreeSet`

  Elements are kept in sorted order

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- Elements are stored in nodes.
- The nodes are arranged in a tree shape,

  Not in a linear sequence

- You can form tree sets for any class that implements the `Comparable` interface:

  Example: `String` or `Integer`.

Sets

- Use a `TreeSet` if you want to visit the set's elements in sorted order.

  Otherwise choose a `HashSet`.

  It is a bit more efficient — if the hash function is well chosen.

Sets

- Store the reference to a `TreeSet` or `HashSet` in a `Set<String>` variable:

```
   Set<String> names = new HashSet<>();
or
   Set<String> names = new TreeSet<>();
```

- After constructing the collection object:

  The implementation no longer matters

  Only the interface is important

Working with Sets

- Adding and removing elements:

```
names.add("Romeo");
names.remove("Juliet");
```

- Sets don't have duplicates.

  Adding a duplicate is ignored.

- Attempting to remove an element that isn't in the set is ignored.
- The `contains` method tests whether an element is contained in the set:

```
if (names.contains("Juliet")) . . .
```

The `contains` method uses the `equals` method of the element type

Working with Sets

- To process all elements in the set, get an iterator.
- A set iterator visits the elements in the order in which the set implementation keeps them.

```
Iterator<String> iter = names.iterator();
while (iter.hasNext())
{
   String name = iter.next();
   Do something with name
}
```

- You can also use the “for each” loop

```
for (String name : names)
{
 Do something with name
}
```

- You cannot add an element to a set at an iterator position - A set is unordered.
- You can remove an element at an iterator position.
- The iterator interface has no `previous` method.

Working with Sets

Table 4 Working with Sets	
`Set<String> names;`	Use the interface type for variable declarations.
`names = new HashSet<>();`	Use a `TreeSet` if you need to visit the elements in sorted order.
`names.add("Romeo");`	Now `names.size()` is 1.
`names.add("Fred");`	Now `names.size()` is 2.
`names.add("Romeo");`	`names.size()` is still 2. You can't add duplicates.
`if (names.contains("Fred"))`	The `contains` method checks whether a value is contained in the set. In this case, the method returns `true`.
`System.out.println(names);`	Prints the set in the format `[Fred, Romeo]`. The elements need not be shown in the order in which they were inserted.

`for (String name : names)`
`{`
`. . .`
`}`
	Use this loop to visit all elements of a set.

`names.remove("Romeo");`	Now `names.size()` is 1.
`names.remove("Juliet");`	It is not an error to remove an element that is not present. The method call has no effect.

SpellCheck Example Program

- Read all the correctly spelled words from a dictionary file

  Put them in a set

- Reads all words from a document

  Put them in a second set

- Print all the words in the second set that are not in the dictionary set.
- Potential misspellings

section_3/SpellCheck.java

```
1  import java.util.HashSet;
2  import java.util.Scanner;
3  import java.util.Set;
4  import java.io.File;
5  import java.io.FileNotFoundException;
6
7  /**
8     This program checks which words in a file are not present in a dictionary.
9  */
10 public class SpellCheck
11 {
12    public static void main(String[] args)
13       throws FileNotFoundException
14    {
15       // Read the dictionary and the document
16
17       Set<String> dictionaryWords = readWords("words");
18       Set<String> documentWords = readWords("alice30.txt");
19
20       // Print all words that are in the document but not the dictionary
21
22       for (String word : documentWords)
23       {
24          if (!dictionaryWords.contains(word))
25          {
26             System.out.println(word);
27          }
28       }
29    }
30
31    /**
32       Reads all words from a file.
33       @param filename the name of the file
34       @return a set with all lowercased words in the file. Here, a
35       word is a sequence of upper- and lowercase letters.
```

Program Run:

```
neighbouring
croqueted
pennyworth
dutchess
comfits
xii
dinn
clamour
```

Maps

- A map allows you to associate elements from a **key set** with elements from a **value collection**.
- Use a map when you want to look up objects by *using a key*.

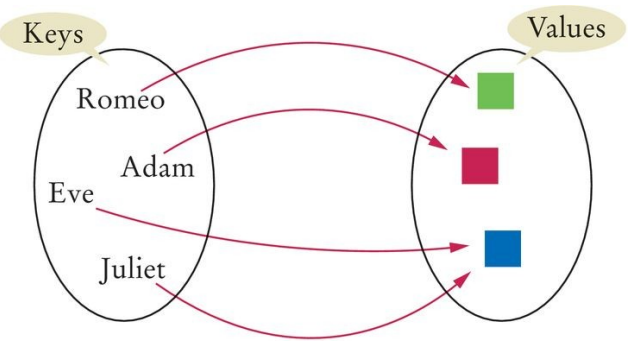

Figure 10 A Map

- Two implementations of the `Map` interface:

  `HashMap`

  `TreeMap`

- Store the reference to the map object in a `Map` reference:

```
Map<String, Color> favoriteColors = new HashMap<>();
```

Maps

- Use the `put` method to add an association:

```
favoriteColors.put("Juliet", Color.RED);
```

- You can change the value of an existing association by calling `put` again:

```
favoriteColors.put("Juliet", Color.BLUE);
```

- The `get` method returns the value associated with a key:

```
Color julietsFavoriteColor = favoriteColors.get("Juliet");
```

- If you ask for a key that isn't associated with any values, the `get` method returns `null`.
- To remove an association, call the `remove` method with the key:

```
favoriteColors.remove("Juliet");
```

Working with Maps

Table 5 Working with Maps	
`Map<String, Integer> scores;`	Keys are strings, values are `Integer` wrappers. Use the interface type for variable declarations.
`scores = new TreeMap<>();`	Use a `HashMap` if you don't need to visit the keys in sorted order.
`scores.put("Harry", 90);` `scores.put("Sally", 95);`	Adds keys and values to the map.
`scores.put("Sally", 100);`	Modifies the value of an existing key.
`int n = scores.get("Sally");` `Integer n2 = scores.get("Diana");`	Gets the value associated with a key, or `null` if the key is not present. `n` is 100, `n2` is `null`.
`System.out.println(scores);`	Prints `scores.toString()`, a string of the form `{Harry=90, Sally=100}`

`for (String key : scores.keySet())`
`{`
`  Integer value = scores.get(key);`
`  . . .`
`}`
	Iterates through all map keys and values.

`scores.remove("Sally");`	Removes the key and value.

Maps

- Sometimes you want to enumerate all keys in a map.
- The `keySet` method yields the set of keys.
- Ask the key set for an iterator and get all keys.
- For each key, you can find the associated value with the `get` method.
- To print all key/value pairs in a map `m`:

```
Set<String> keySet = m.keySet();
for (String key : keySet)
{
   Color value = m.get(key);
   System.out.println(key + "->" + value);
}
```

section_4/MapDemo.java

```
1  import java.awt.Color;
2  import java.util.HashMap;
3  import java.util.Map;
4  import java.util.Set;
5
6  /**
7     This program demonstrates a map that maps names to colors.
8  */
9  public class MapDemo
10 {
11    public static void main(String[] args)
12    {
13       Map<String, Color> favoriteColors = new HashMap<>();
14       favoriteColors.put("Juliet", Color.BLUE);
15       favoriteColors.put("Romeo", Color.GREEN);
16       favoriteColors.put("Adam", Color.RED);
17       favoriteColors.put("Eve", Color.BLUE);
18
19       // Print all keys and values in the map
20
21       Set<String> keySet = favoriteColors.keySet();
22       for (String key : keySet)
23       {
24          Color value = favoriteColors.get(key);
25          System.out.println(key + " : " + value);
26       }
27    }
28 }
```

Program Run:

```
Juliet : java.awt.Color[r=0,g=0,b=255]
Adam : java.awt.Color[r=255,g=0,b=0]
Eve : java.awt.Color[r=0,g=0,b=255]
Romeo : java.awt.Color[r=0,g=255,b=0]
```

Choosing a Collection

1. Determine how you access the values.
2. Determine the element types or key/value types.
3. Determine whether element or key order matters.
4. For a collection, determine which operations must be efficient.
5. For hash sets and maps, decide whether you need to implement the hashCode and equals methods.
6. If you use a tree, decide whether to supply a comparator.

Hash Functions

- You may need to implement a hash function for your own classes.
- **A hash function**: a function that computes an integer value, the hash code, from an object in such a way that different objects are likely to yield different hash codes.
- `Object` class has a `hashCode` method

  you need to override it to use your class in a hash table
- A collision: two or more objects have the same hash code.
- The method used by the `String` class to compute the hash code.

```
final int HASH_MULTIPLIER = 31;
int h = 0;
for (int i = 0; i < s.length(); i++)
{
   h = HASH_MULTIPLIER * h + s.charAt(i);
}
```

- This produces different hash codes for `"tea"` and `"eat"`.

Hash Functions

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A good hash function produces different hash values for each object so that they are scattered about in a hash table.

Hash Functions

- Override `hashCode` methods in your own classes by combining the hash codes for the instance variables.
- A hash function for our `Country` class:

```
public class Country
{
   public int hashCode()
   {
      int h1 = name.hashCode();
      int h2 = new Double(area).hashCode();
      final int HASH_MULTIPLIER = 29;
      int h = HASH_MULTIPLIER * h1 + h2;
      return h;
   }
}
```

- Easier to use `Objects.hash()` method
  - Takes hashcode of all arguments and multiplies them:

```
public int hashCode()
{
   return Objects.hash(name, area);
}
```

- A class's `hashCode` method must be compatible with its `equals` method.

Stacks

- A stack lets you insert and remove elements only at one end:

  Called the top of the stack.

  Removes items in the opposite order than they were added

  Last-in, first-out or LIFO order

- Add and remove methods are called `push` and `pop`.

- Example

```
Stack<String> s = new Stack<>();
s.push("A"); s.push("B"); s.push("C");
while (s.size() > 0)
{
   System.out.print(s.pop() + " "); // Prints C B A
}
```

- The last pancake that has been added to this stack will be the first one that is consumed.

Stacks

- Many applications for stacks in computer science.
- Consider: Undo function of a word processor

  The issued commands are kept in a stack.

  When you select “Undo”, the **last** command is popped off the stack and undone.

- Run-time stack that a processor or virtual machine:

  Stores the values of variables in nested methods.

  When a new method is called, its parameter variables and local variables are pushed onto a stack.

  When the method exits, they are popped off again.

Stack in the Java Library

- `Stack` class provides `push`, `pop` and `peek` methods.

Table 7 Working with Stacks

`Stack<Integer> s = new Stack<>();`	Constructs an empty stack.

`s.push(1);`
`s.push(2);`
`s.push(3);`
	Adds to the top of the stack; `s` is now `[1, 2, 3]`. (Following the `toString` method of the `Stack` class, we show the top of the stack at the end.)

`int top = s.pop();`	Removes the top of the stack; `top` is set to 3 and `s` is now `[1, 2]`.
`head = s.peek();`	Gets the top of the stack without removing it; `head` is set to 2.

Queue

- A queue
  - Lets you add items to one end of the queue (the tail)
  - Remove items from the other end of the queue (the head)
  - Items are removed in the same order in which they were added
  - First-in, first-out or FIFO order
- To visualize a queue, think of people lining up.

Photodisc/Punchstock.

- Typical application: a print queue.

Queue

- The `Queue` interface in the standard Java library has:
  - an `add` method to add an element to the tail of the queue,
  - a `remove` method to remove the head of the queue, and
  - a `peek` method to get the head element of the queue without removing it.
- The `LinkedList` class implements the `Queue` interface.
- When you need a queue, initialize a `Queue` variable with a `LinkedList` object:

```
Queue<String> q = new LinkedList<>();
q.add("A"); q.add("B"); q.add("C");
while (q.size() > 0) { System.out.print(q.remove() + " "); } // Prints A B C
```

Table 8 Working with Queues

`Queue<Integer> q = new LinkedList<>();`	The `LinkedList` class implements the `Queue` interface.

`q.add(1);`
`q.add(2);`
`q.add(3);`
	Adds to the tail of the queue; `q` is now `[1, 2, 3]`.

`int head = q.remove();`	Removes the head of the queue; `head` is set to 1 and `q` is `[2, 3]`.
`head = q.peek();`	Gets the head of the queue without removing it; `head` is set to 2.

Priority Queues

- A priority queue collects elements, each of which has a priority.
- Example: a collection of work requests, some of which may be more urgent than others.
- *Does not* maintain a first-in, first-out discipline.
- Elements are retrieved according to their priority.

  Priority 1 denotes the most urgent priority.

  Each removal extracts the minimum element.
- When you retrieve an item from a priority queue, you always get the most urgent one.
- Elements should belong to a class that implements the `Comparable` interface.

Priority Queues

- Example: objects of a class `WorkOrder` into a priority queue.

```
PriorityQueue<WorkOrder> q = new PriorityQueue<>();
q.add(new WorkOrder(3, "Shampoo carpets"));
q.add(new WorkOrder(1, "Fix broken sink"));
q.add(new WorkOrder(2, "Order cleaning supplies"));
```

- When calling `q.remove()` for the first time, the work order with priority 1 is removed.

Table 9 Working with Priority Queues

`PriorityQueue<Integer> q = new PriorityQueue<>();`	This priority queue holds `Integer` objects. In practice, you would use objects that describe tasks.
`q.add(3); q.add(1); q.add(2);`	Adds values to the priority queue.
`int first = q.remove();` `int second = q.remove();`	Each call to `remove` removes the most urgent item: `first` is set to 1, `second` to 2.
`int next = q.peek();`	Gets the smallest value in the priority queue without removing it.

Stack and Queue Applications

- A stack can be used to check whether parentheses in an expression are balanced.

```
When you see an opening parenthesis, push it on the stack.
When you see a closing parenthesis, pop the stack.
If the opening and closing parentheses don't match
  The parentheses are unbalanced. Exit.
If at the end the stack is empty
  The parentheses are balanced.
Else
  The parentheses are not balanced.
```

- Walkthrough of the sample expression:

Stack	Unread expression	Comments
Empty	-{ [b * b - (4 * a * c)] / (2 * a) }	
{	[b * b - (4 * a * c)] / (2 * a) }	
{ [	b * b - (4 * a * c)] / (2 * a) }	
{ [(	4 * a * c)] / (2 * a) }	
{ [	] / (2 * a) }	(matches)
{	/ (2 * a) }	[matches]
{ (	2 * a) }	
{	}	(matches)
Empty	No more input	{ matches }
		The parentheses are balanced

Stack and Queue Applications

- Use a stack to evaluate expressions in reverse Polish notation (also known as Postfix notation)
- 3 – 4 × 5 is written as 3 4 5 x –
- (3 - 4) x 5 is written as 3 4 – 5 x or 5 3 4 - x

```
If you read a number
  Push it on the stack.
Else if you read an operand
  Pop two values off the stack.
  Combine the values with the operand.
  Push the result back onto the stack.
Else if there is no more input
  Pop and display the result.
```

- Walkthrough of evaluating the expression 3 4 5 + ×:

Stack	Unread expression	Comments
Empty	3 4 5 + x	
3	4 5 + x	Numbers are pushed on the stack
3 4	5 + x	
3 4 5	+ x	
3 9	x	Pop 4 and 5, push 4 5 +
27	No more input	Pop 3 and 9, push 3 9 x
Empty		Pop and display the result, 27

section_6_2/Calculator.java

```
1  import java.util.Scanner;
2  import java.util.Stack;
3
4  /**
5     This calculator uses the reverse Polish notation.
6  */
7  public class Calculator
8  {
9     public static void main(String[] args)
10    {
11       Scanner in = new Scanner(System.in);
12       Stack<Integer> results = new Stack<>();
13       System.out.println("Enter one number or operator per line, Q to quit. ");
14       boolean done = false;
15       while (!done)
16       {
17          String input = in.nextLine();
18
19          // If the command is an operator, pop the arguments and push the result
20
21          if (input.equals("+"))
22          {
23             results.push(results.pop() + results.pop());
24          }
25          else if (input.equals("-"))
26          {
27             Integer arg2 = results.pop();
28             results.push(results.pop() - arg2);
29          }
30          else if (input.equals("*") || input.equals("x"))
31          {
32             results.push(results.pop() * results.pop());
33          }
34          else if (input.equals("/"))
35          {
36             Integer arg2 = results.pop();
```

Evaluating Algebraic Expressions with Two Stacks

- Using two stacks, you can evaluate expressions in standard algebraic notation.

One stack for numbers, one for operators

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- Evaluating the top: 3 + 4

	Number stack Empty	Operator stack Empty	Unprocessed input 3 + 4	Comments
1	3		+ 4	
2	3	+	4	
3	4 3	+	No more input	Evaluate the top.
4	7			The result is 7.

Evaluating Algebraic Expressions with Two Stacks

- Evaluate 3 x 4 + 5

Push until you get to the +

	Number stack Empty	Operator stack Empty	Unprocessed input 3 × 4 + 5	Comments
1	3		× 4 + 5	
2	3	×	4 + 5	
3	4 3	×	+ 5	Evaluate × before +.

x (top of operator stack) has higher precedence than + , so evaluate the top

	Number stack	Operator stack		Comments
4	12	+	5	
5	5 12	+	No more input	Evaluate the top.
6	17			That is the result.

Evaluating Algebraic Expressions with Two Stacks

- Evaluate 3 + 4 × 5

Add x to the operator stack so we can get the next number

	Number stack Empty	Operator stack Empty	Unprocessed input 3 + 4 × 5	Comments
1	3		+ 4 × 5	
2	3	+	4 + 5	
3	4 3	+	× 5	Don't evaluate + yet.
4	4 3	× +	5	

Keep operators on the stack until they are ready to be evaluated

	Number stack	Operator stack		Comments
5	5 4 3	× +	No more input	Evaluate the top.
6	20 3	+		Evaluate top again.
7	23			That is the result.

Evaluating Algebraic Expressions with Two Stacks

- Evaluating parentheses: 3 × (4 + 5)

Push (on the stack

Keep pushing until we reach the)

Evaluate until we find the matching (

	Number stack Empty	Operator stack Empty	Unprocessed input 3 × (4 + 5)	Comments
1	3		× (4 + 5)	
2	3	×	(4 + 5)	
3	3	(×	4 + 5)	Don't evaluate × yet.
4	4 3	(×	+ 5)	
5	4 3	+ (×	5)	
6	5 4 3	+ (×	)	Evaluate the top.
7	9 3	(×	No more input	Pop (.
8	9 3	×		Evaluate top again.
9	27			That is the result.

Evaluating Algebraic Expressions with Two Stacks

- The algorithm

```
If you read a number
  Push it on the number stack.
Else if you read a (
  Push it on the operator stack.
Else if you read an operator op
  While the top of the stack has a higher precedence than op
    Evaluate the top.
  Push op on the operator stack.
Else if you read a )
  While the top of the stack is not a (
    Evaluate the top.
  Pop the (.
Else if there is no more input
  While the operator stack is not empty
    Evaluate the top.
```

- At the end, the value on the number stack is the value of the expression.

- Helper method to evaluate the top:

```
Pop two numbers off the number stack.
Pop an operator off the operator stack.
Combine the numbers with that operator.
Push the result on the number stack.
```

Backtracking

- Use a stack to remember choices you haven't yet made so that you can backtrack to them.
- Escaping a maze

  You want to escape from a maze.

  You come to an intersection. What should you do?

  Explore one of the paths.

  But remember the other paths.

  If your chosen path doesn't work, you can

  - go back and try one of the other choices.

- Use a stack to remember the paths that still need to be tried.
- The process of returning to a choice point and trying another choice is called **backtracking**.

Backtracking - Maze Example

- Start, at position (3, 4).
- There are four possible paths. We push them all on a stack (1).
- We pop off the topmost one, traveling north from (3, 4).
- Following this path leads to position (1, 4).

  We now push two choices on the stack, going west or east (2).

  Both of them lead to dead ends (3) (4).

- Now we pop off the path from (3,4) going east.

  That too is a dead end (5).

- Next is the path from (3, 4) going south.
- Comes to an intersection at (5, 4).

  Both choices are pushed on the stack (6).

  They both lead to dead ends (7) (8).

- Finally, the path from (3, 4) going west leads to an exit (9).

Backtracking

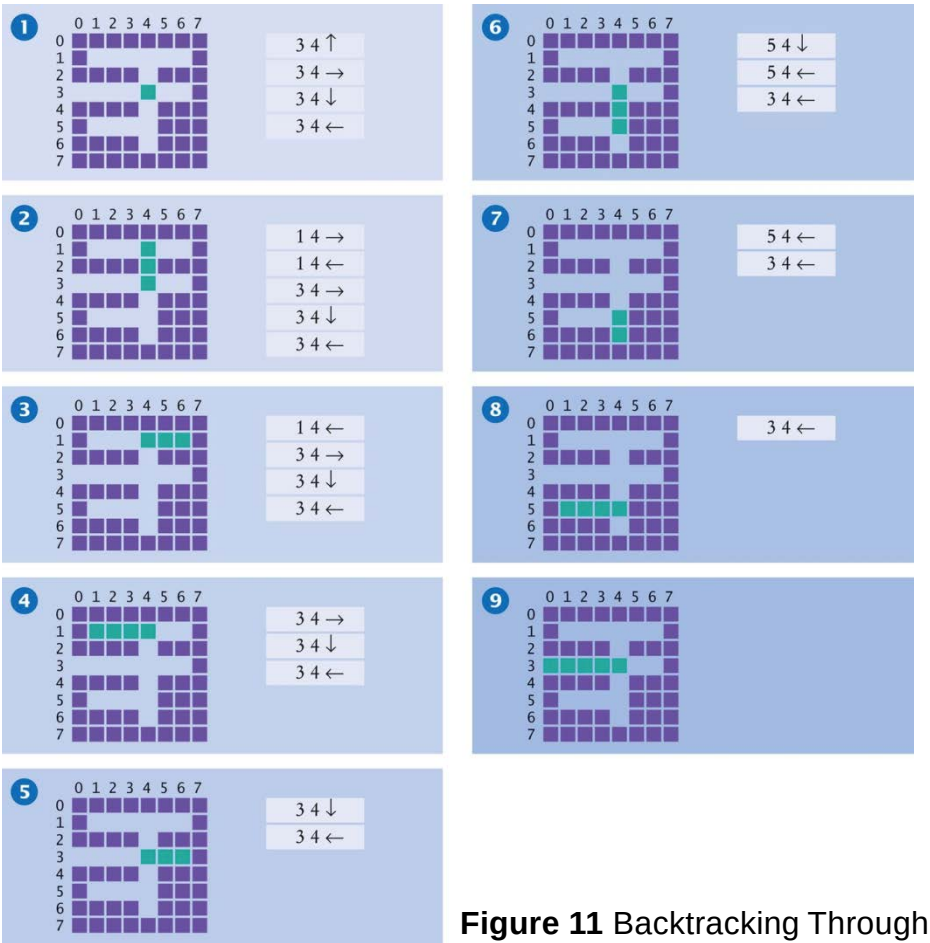

Figure 11 Backtracking Through a Maze

Backtracking

- Algorithm:

```
Push all paths from the point on which you are
standing on a stack.  While the stack is not
empty
  Pop a path from the stack.
  Follow the path until you reach an exit,
  intersection, or dead end.  If you found an exit
    Congratulations!
Else if you found an intersection
  Push all paths meeting at the intersection, except the current one, onto the  stack.
```

- This works if there are no cycles in the maze.

  You never circle back to a previously visited intersection

- You could use a queue instead of a stack.