CHAPTER 15

THE JAVA COLLECTIONS FRAMEWORK

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Chapter Goals

- 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

Contents

- An Overview of the Java Collections Framework
- Linked Lists
- Sets
- Maps
- Stacks Queues and Priority Queues
- Stack and Queue Applications

In this chapter, you will learn about the Java collection framework, a hierarchy of interface types and classes for collecting objects

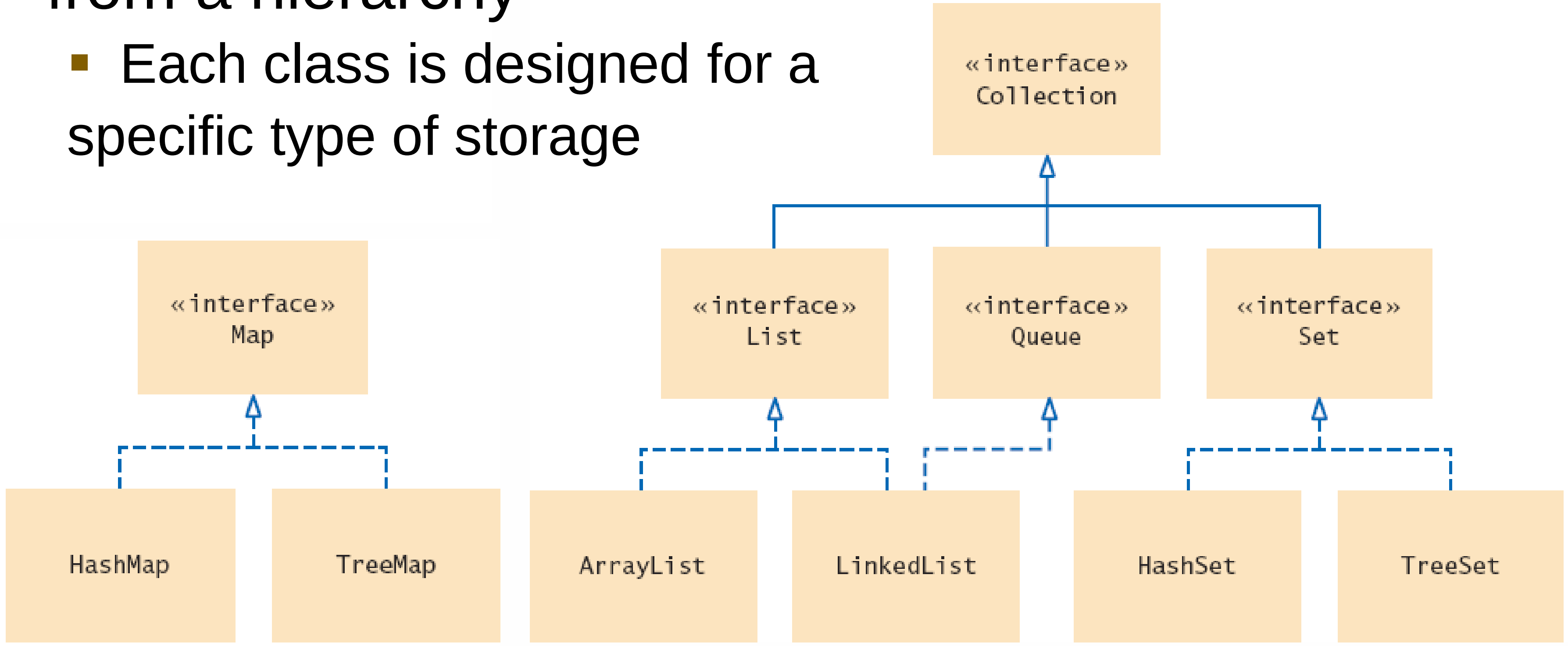
15.1 Java Collections Framework

- When you need to organize multiple objects in your program, you can place them into a collection
- The `ArrayList` class that was introduced in Chapter 6 is one of many collection classes that the standard Java library supplies
- Each interface type is implemented by one or more classes

A collection groups together elements and allows them to be accessed and retrieved later

Collections Framework Diagram

- Each collection class implements an interface from a hierarchy
  - Each class is designed for a specific type of storage



Lists and Sets

- Ordered Lists

  - `ArrayList`
    - Stores a list of items in a dynamically sized array
  - `LinkedList`
    - Allows speedy insertion and removal of items from the list

A **list** is a collection that maintains the order of its elements.

Lists and Sets

- Unordered Sets

  - `HashSet`
    - Uses hash tables to speed up finding, adding, and removing elements
  - `TreeSet`
    - Uses a binary tree to speed up finding, adding, and removing elements

A **set** is an unordered collection of unique elements.

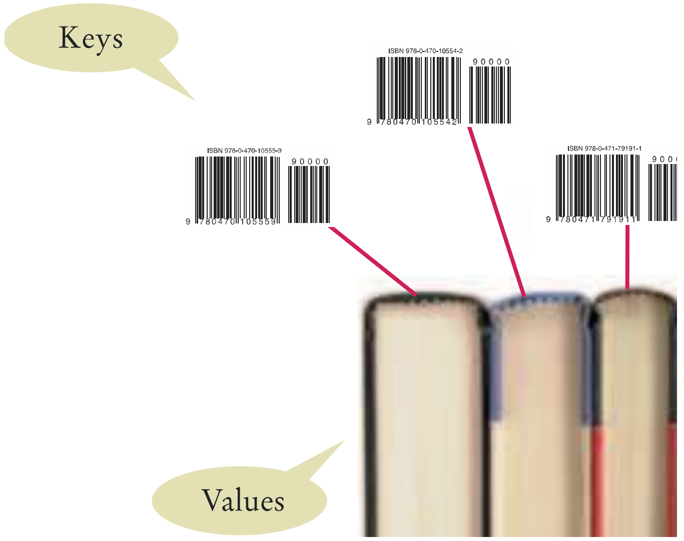
Stacks and Queues

- Another way of gaining efficiency in a collection is to reduce the number of operations available
- Two examples are:
  - Stack
    - Remembers the order of its elements, but it does not allow you to insert elements in every position
    - You can only add and remove elements at the top
  - Queue
    - Add items to one end (the tail)
    - Remove them from the other end (the head)
    - Example: A line of people waiting for a bank teller

Maps

- A map stores keys, values, and the associations between them
  - Example:
  - Barcode keys and books

A map keeps associations between key and value objects.



- Keys
  - Provides an easy way to represent an object (such as a numeric bar code)
- Values
  - The actual object that is associated with the key

The Collection Interface (1)

- `List`, `Queue` and `Set` are specialized interfaces that inherit from the `Collection` interface
  - All share the following commonly used methods

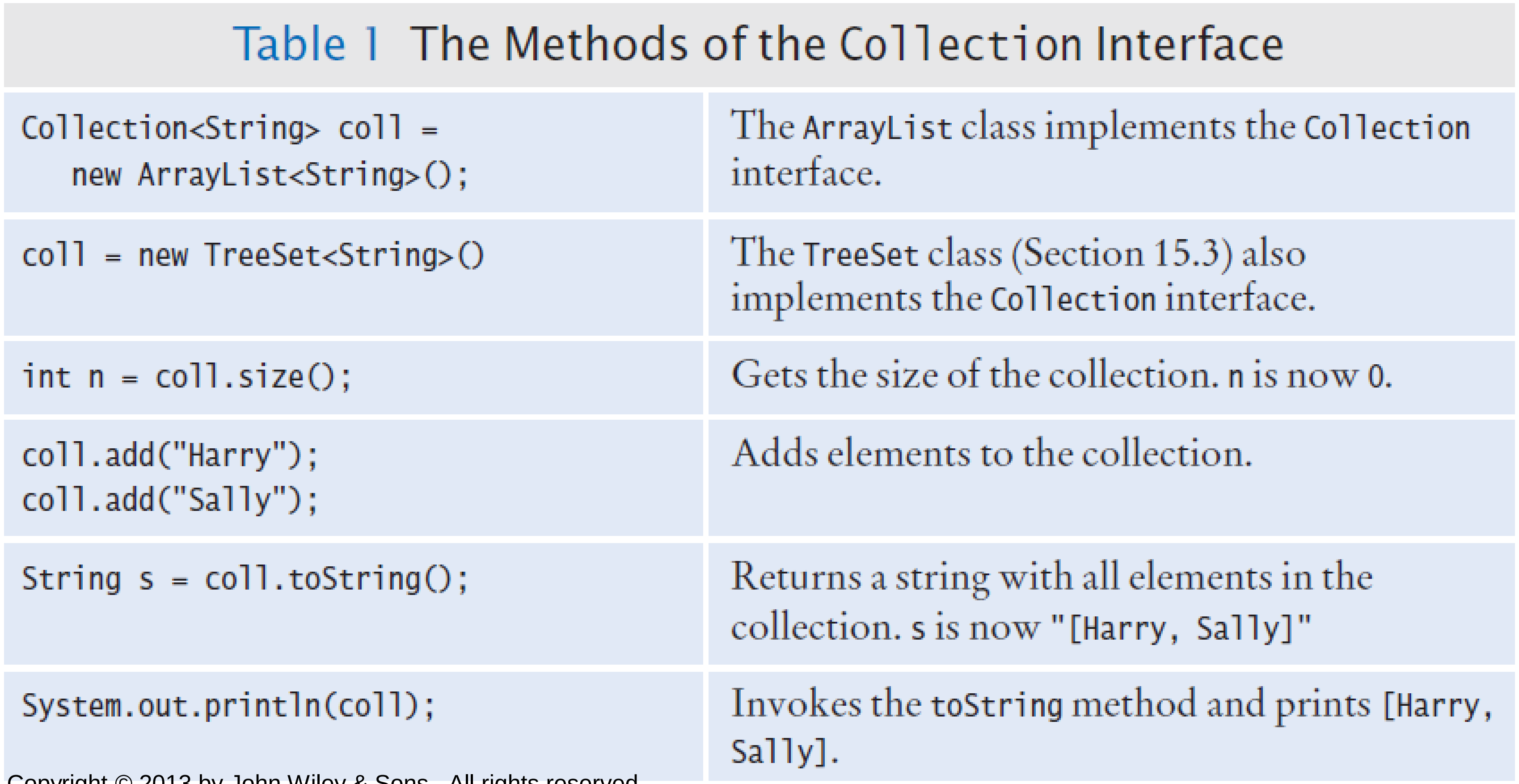


Table 1 The Methods of the Collection Interface

`Collection<String> coll = new ArrayList<String>();`	The `ArrayList` class implements the `Collection` interface.
`coll = new TreeSet<String>()`	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]`.

The Collection Interface (2)

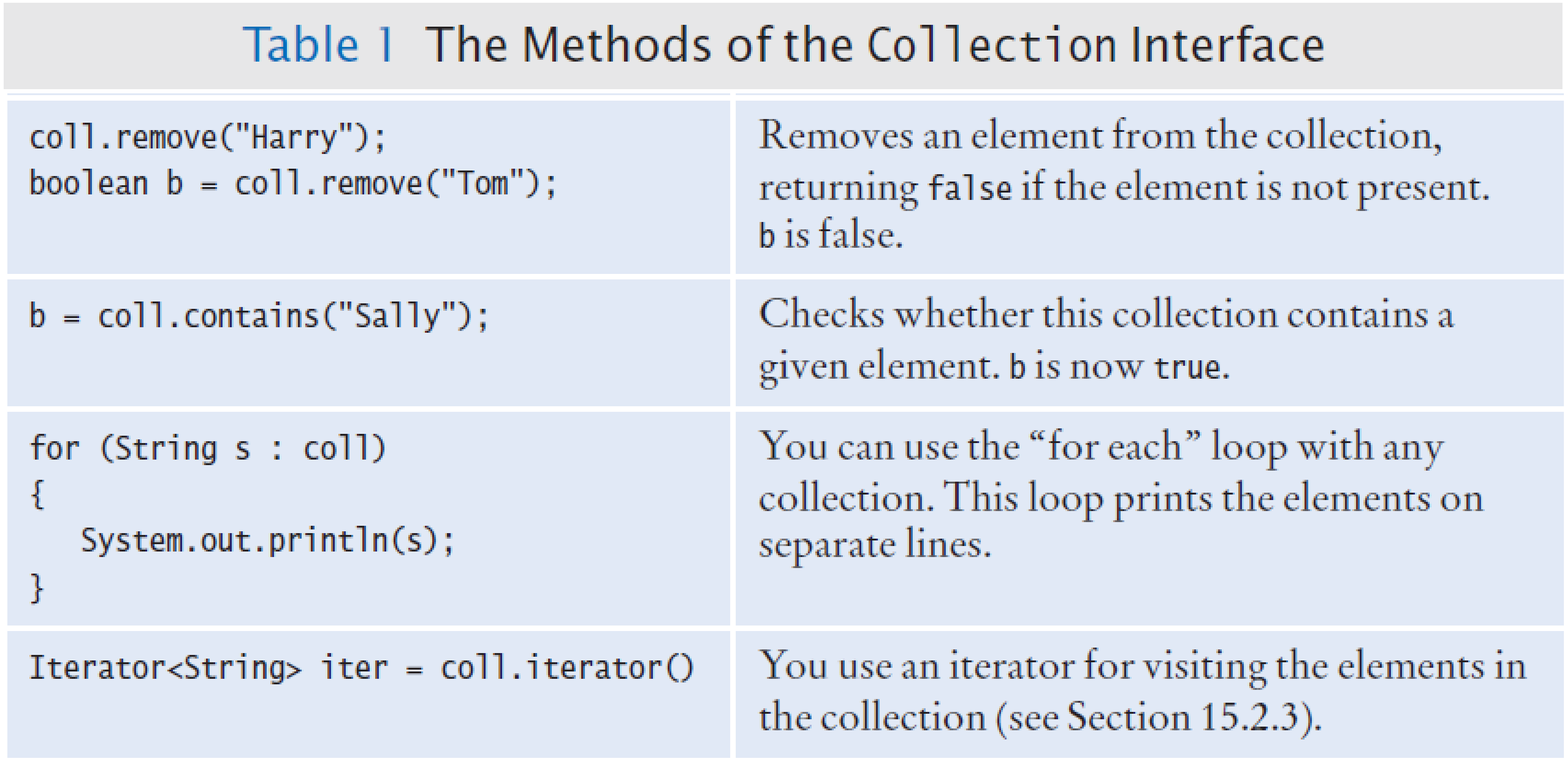


Table 1 The Methods of the Collection Interface

`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.

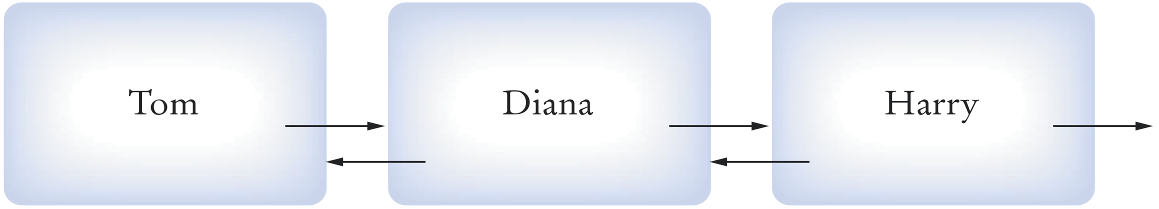
`b = coll.contains("Sally");`	Checks whether this collection contains a given element. `b` is now `true`.

`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.

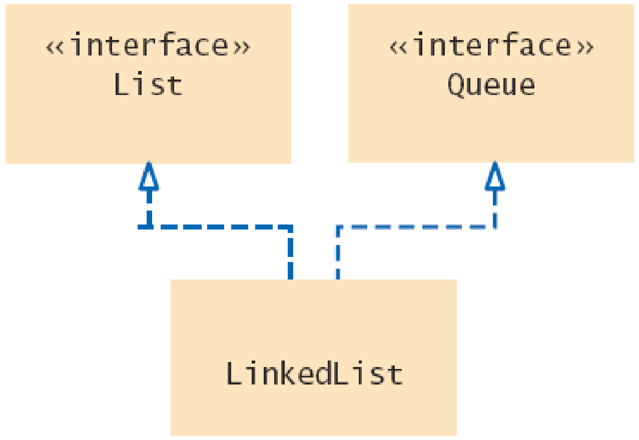
`Iterator<String> iter = coll.iterator()`	You use an iterator for visiting the elements in the collection (see Section 15.2.3).

15.2 Linked Lists

- Linked lists use references to maintain an ordered lists of ‘nodes’
  - The ‘head’ of the list references the first node
  - Each node has a value and a reference to the next node

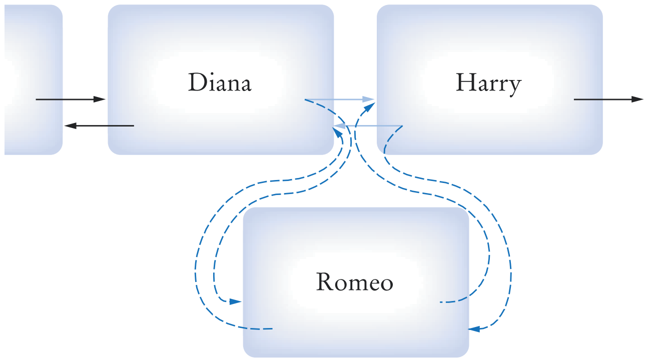


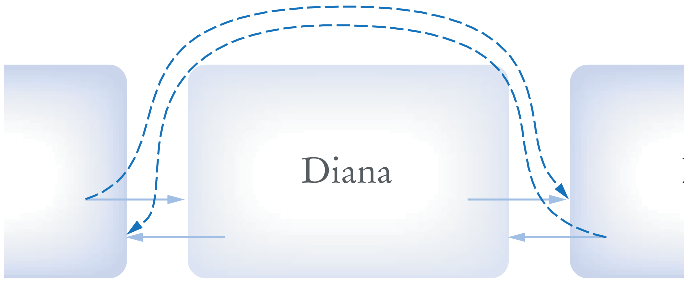
  - They can be used to implement
    - A `List` Interface
    - A `Queue` Interface



Linked Lists Operations

- Efficient Operations
  - Insertion of a node
    - Find the elements it goes between
    - Remap the references
  - Removal of a node
    - Find the element to remove
    - Remap neighbor's references
  - Visiting all elements in order





- Inefficient Operations
  - Random access

Each instance variable is declared just like other variables we have used.

`LinkedList`: Important Methods

Table 2 Working with Linked Lists

`LinkedList<String> list = new LinkedList<String>();`	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 676).

Generic Linked Lists

- The Collection Framework uses Generics
  - Each list is declared with a type field in < > angle brackets

```
LinkedList<String> employeeNames = . . .;
```

```
LinkedList<String>
LinkedList<Employee>
```

List Iterators

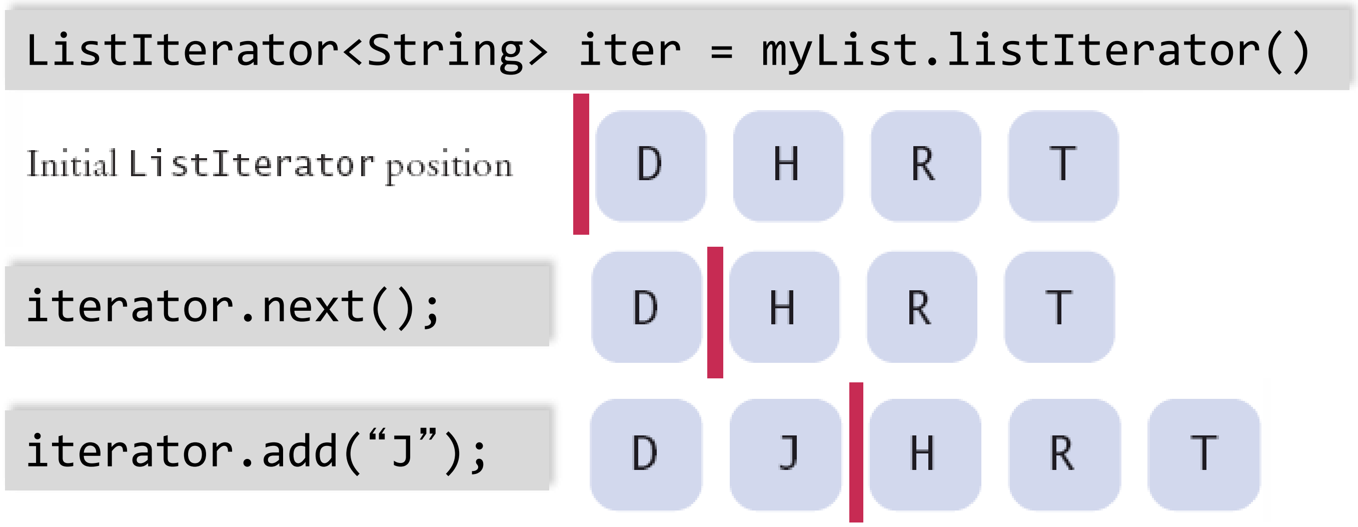
- When traversing a `LinkedList`, use a `ListIterator`
  - Keeps track of where you are in the list.

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

- Use an iterator to:
  - Access elements inside a linked list
  - Visit other than the first and the last nodes

Using Iterators

- Think of an iterator as pointing **between** two elements


ListIterator<String> iter = myList.listIterator()
Initial ListIterator position
D H R T
iterator.next();
D H R T
iterator.add("J");
D J H R T

- Note that the generic type for the `listIterator` must match the generic type of the `LinkedList`

Iterator and ListIterator Methods

- Iterators allow you to move through a list easily
  - Similar to an index variable for an array

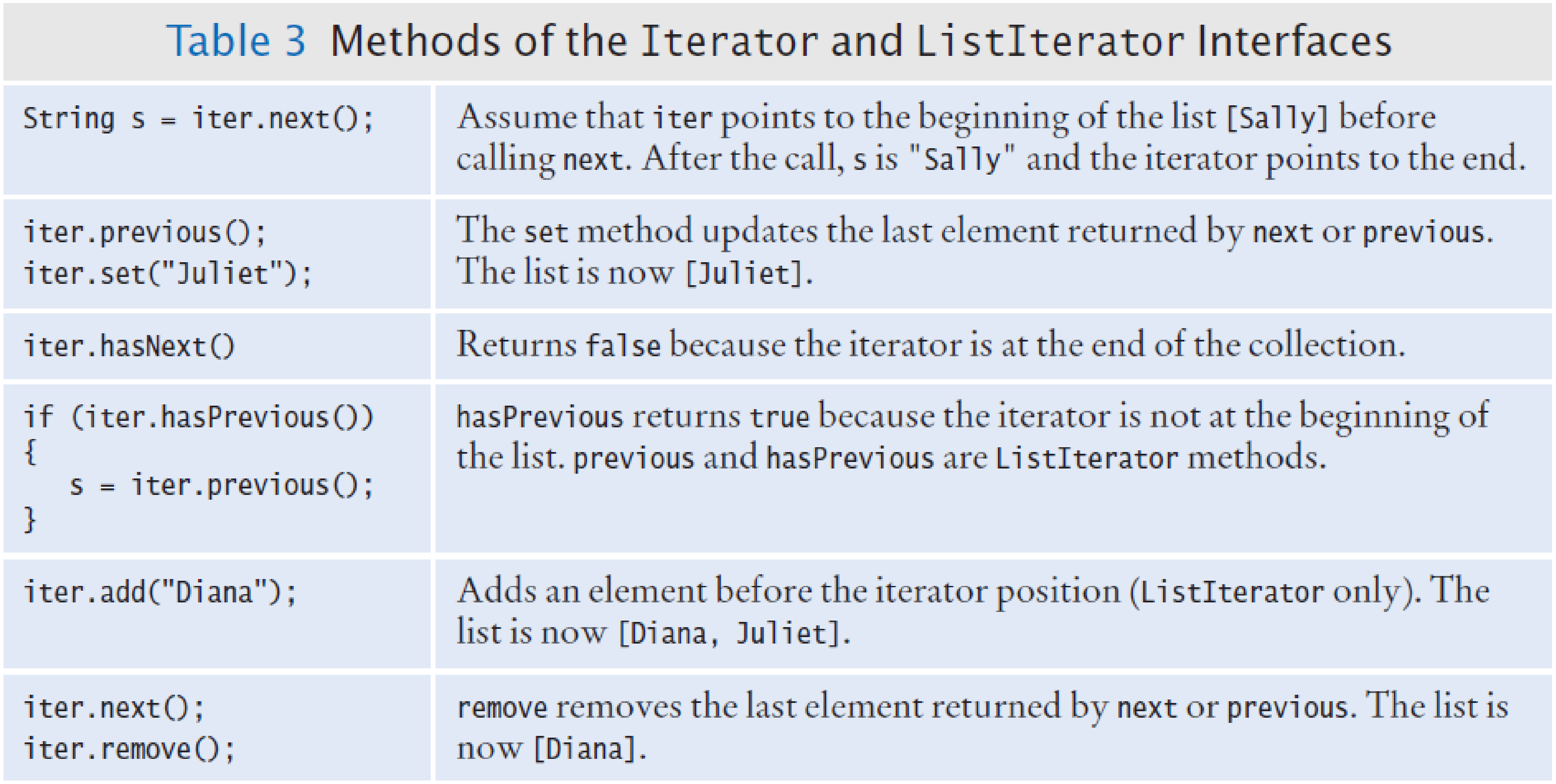


Table 3 Methods of the Iterator and ListIterator Interfaces

`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]`.

Iterators and Loops

- Iterators are often used in while and "for-each" loops
  - `hasNext` returns true if there is a next element
  - `next` returns a reference to the value of the next element

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

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

  - Where is the iterator in the "for-next" loop?
    - It is used 'behind the scenes'

Adding and Removing with Iterators

- Adding

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

  - A new node is added AFTER the Iterator
  - The Iterator is moved past the new node
- Removing
  - Removes the object that was returned with the last call to `next` or `previous`
  - It can be called only once after `next` or `previous`
  - You cannot call it immediately after a call to `add`.

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

If you call the `remove` method improperly, it throws an `IllegalStateException`.

ListDemo.java (1)

- Illustrates adding, removing and printing a list

```java
import java.util.LinkedList;
import java.util.ListIterator;

/**
   This program demonstrates the LinkedList class.
*/
public class ListDemo
{
   public static void main(String[] args)
   {
      LinkedList<String> staff = new LinkedList<String>();
      staff.addLast("Diana");
      staff.addLast("Harry");
      staff.addLast("Romeo");
      staff.addLast("Tom");

      // | in the comments indicates the iterator position

      ListIterator<String> iterator = staff.listIterator(); // |DHRT
      iterator.next(); // D|HRT
      iterator.next(); // DH|RT

```

ListDemo.java (2)

```
        // Add more elements after second element

        iterator.add("Juliet"); // DHJ|RT
        iterator.add("Nina"); // DHJN|RT

        iterator.next(); // DHJNR|T

        // Remove last traversed element

        iterator.remove(); // DHJN|T

        // Print all elements

        System.out.println(staff);
        System.out.println("Expected: [Diana, Harry, Juliet, Nina, Tom]");
    }
}
```

Program Run

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

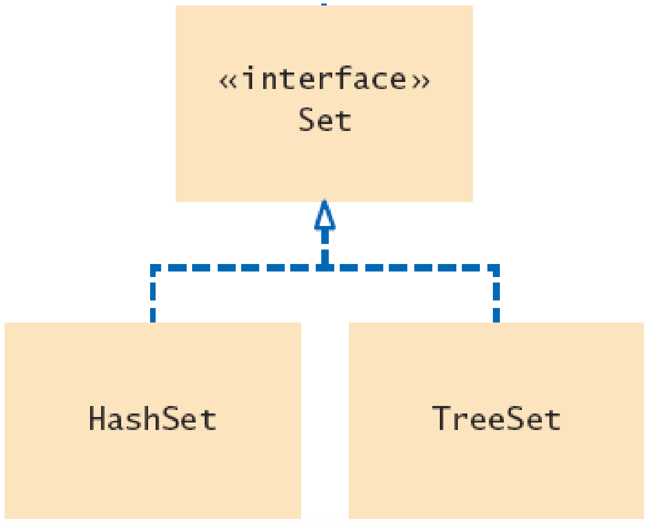
15.3 Sets

- A set is an unordered collection
  - It does not support duplicate elements
- The collection does not keep track of the order in which elements have been added
  - Therefore, it can carry out its operations more efficiently than an ordered collection

The `HashSet` and `TreeSet` classes both implement the Set interface.

Sets

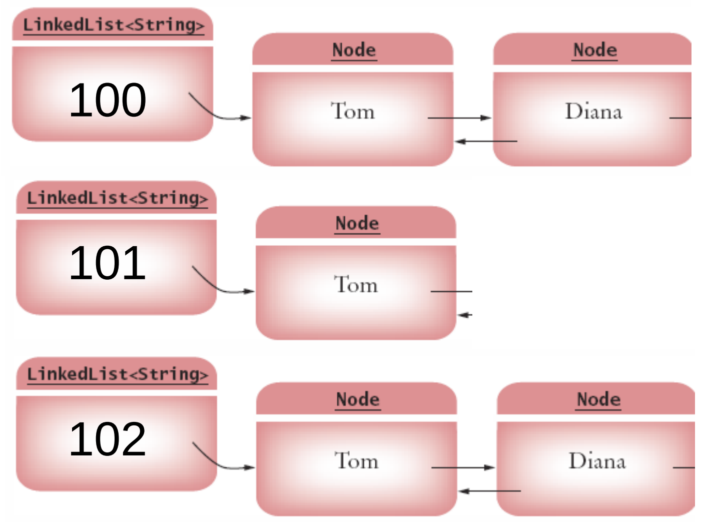
- `HashSet`: Stores data in a Hash Table
- `TreeSet`: Stores data in a Binary Tree
- Both implementations arrange the set elements so that finding, adding, and removing elements is efficient



Set implementations arrange the elements so that they can locate them quickly

Hash Table Concept

- Set elements are grouped into smaller collections of elements that share the same characteristic
  - It is usually based on the result of a mathematical calculation on the contents that results in an integer value
  - In order to be stored in a hash table, elements must have a method to compute their integer values



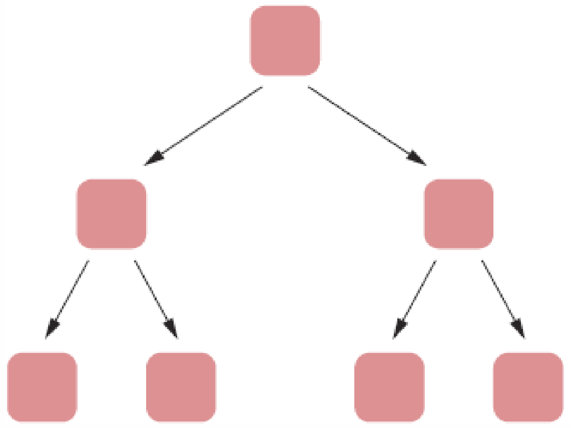
hashCode

- The method is called `hashCode`
  - If multiple elements have the same hash code, they are stored in a Linked list
- The elements must also have an `equals` method for checking whether an element equals another like:
  - String, Integer, Point, Rectangle, Color, and all collection classes

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

Tree Concept

- Set elements are kept in sorted order
  - Nodes are not arranged in a linear sequence but in a tree shape



  - In order to use a `TreeSet`, it must be possible to compare the elements and determine which one is "larger"

TreeSet

- Use `TreeSet` for classes that implement the `Comparable` interface
  - `String` and `Integer`, for example
  - The nodes are arranged in a ‘tree’ fashion so that each ‘parent’ node has up to two child nodes.
    - The node to the left always has a ‘smaller’ value
    - The node to the right always has a ‘larger’ value

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

Iterators and Sets

- Iterators are also used when processing sets
  - `hasNext` returns true if there is a next element
  - `next` returns a reference to the value of the next element
  - `add` via the iterator is not supported for TreeSet and HashSet

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

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

- Note that the elements are not visited in the order in which you inserted them.
- They are visited in the order in which the set keeps them:
  - Seemingly random order for a HashSet
  - Sorted order for a TreeSet

Working With Sets (1)

Table 4 Working with Sets

`Set<String> names;`	Use the interface type for variable declarations.
`names = new HashSet<String>();`	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`.

Working With Sets (2)

Table 4 Working with Sets

`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.java (1)

```
import java.util.HashSet;
import java.util.Scanner;
import java.util.Set;
import java.io.File;
import java.io.FileNotFoundException;

/**
   This program checks which words in a file are not present in a dictionary.
*/
public class SpellCheck
{
   public static void main(String[] args)
      throws FileNotFoundException
   {
      // Read the dictionary and the document

      Set<String> dictionaryWords = readWords("words");
      Set<String> documentWords = readWords("alice30.txt");

      // Print all words that are in the document but not the dictionary

      for (String word : documentWords)
      {
         if (!dictionaryWords.contains(word))
         {
            System.out.println(word);
         }
      }
```

SpellCheck.java (2)

```
   }

   /**
      Reads all words from a file.
      @param filename the name of the file
      @return a set with all lowercased words in the file. Here, a
      word is a sequence of upper- and lowercase letters.
   */
   public static Set<String> readWords(String filename)
      throws FileNotFoundException
   {
      Set<String> words = new HashSet<String>();
      Scanner in = new Scanner(new File(filename));
      // Use any characters other than a-z or A-Z as delimiters
      in.useDelimiter("[^a-zA-Z]+");
      while (in.hasNext())
      {
         words.add(in.next().toLowerCase());
      }
      return words;
   }
}
```

Program Run

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

Programming Tip 15.1

- Use Interface References to Manipulate Data Structures
  - It is considered good style to store a reference to a `HashSet` or `TreeSet` in a variable of type `Set`.

```
Set<String> words = new HashSet<String>();
```

    - This way, you have to change only one line if you decide to use a `TreeSet` instead.

Programming Tip 15.1 (continued)

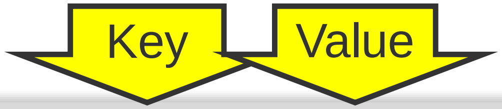
- Unfortunately the same is not true of the `ArrayList`, `LinkedList` and `List` classes
  - The `get` and `set` methods for random access are very inefficient
- Also, if a method can operate on arbitrary collections, use the `Collection` interface type for the parameter:

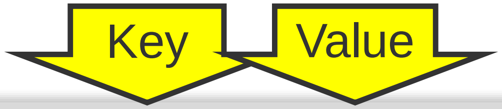
```
public static void removeLongWords(Collection<String> words)
```

15.4 Maps

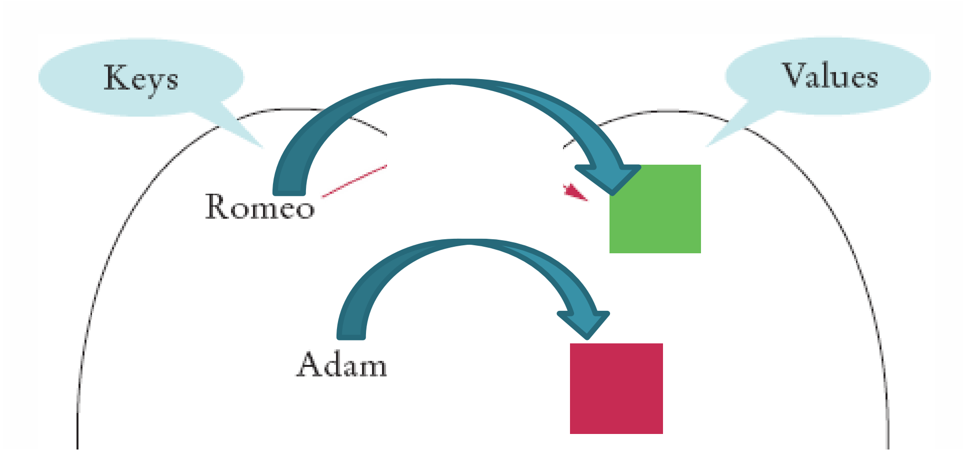
- A map allows you to associate elements from a key set with elements from a value collection.
  - The `HashMap` and `TreeMap` classes both implement the `Map` interface.
  - Use a map to look up objects by using a key.

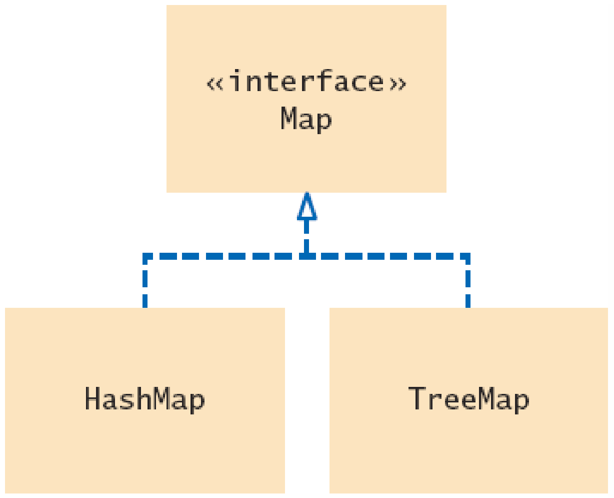
Maps





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





Working with Maps (Table 5)

`Map<String, Integer> scores;`	Keys are strings, values are `Integer` wrappers. Use the interface type for variable declarations.
`scores = new TreeMap<String, Integer>();`	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`.

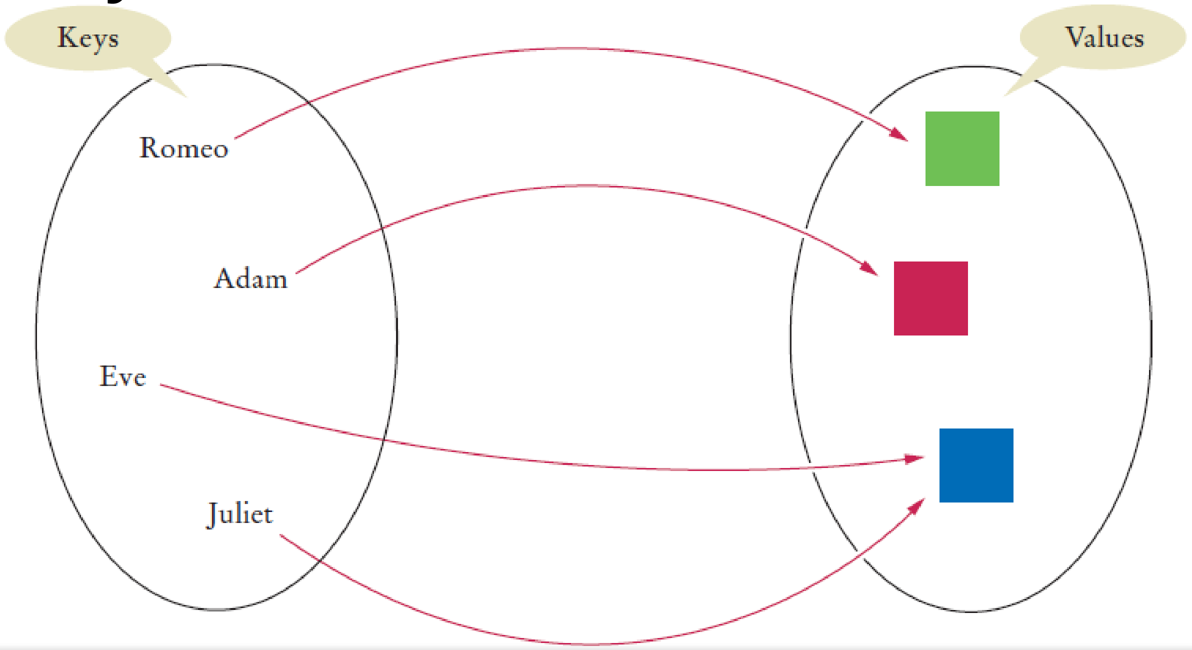
`System.out.println(scores);`	Prints `scores.toString()`, a string of the form `{Harry=90, Sally=100}`

`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.

Key Value Pairs in Maps

- Each key is associated with a value



```
Map<String, Color> favoriteColors = new HashMap<String, Color>();
favoriteColors.put("Juliet", Color.RED);
favoriteColors.put(“Romeo", Color.GREEN);
Color julietsFavoriteColor = favoriteColors.get("Juliet");
favoriteColors.remove("Juliet");
```

Iterating through Maps

- To iterate through the map, use a `keySet` to get the list of keys:

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

To find all values in a map, iterate through the key set and find the values that correspond to the keys.

MapDemo.java

```java
import java.awt.Color;
import java.util.HashMap;
import java.util.Map;
import java.util.Set;

/**
   This program demonstrates a map that maps names to colors.
*/
public class MapDemo
{
   public static void main(String[] args)
   {
      Map<String, Color> favoriteColors = new HashMap<String, Color>();
      favoriteColors.put("Juliet", Color.BLUE);
      favoriteColors.put("Romeo", Color.GREEN);
      favoriteColors.put("Adam", Color.RED);
      favoriteColors.put("Eve", Color.BLUE);

      // Print all keys and values in the map

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

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]
```

Steps to Choosing a Collection

1) Determine how you access values
- Values are accessed by an integer position. Use an `ArrayList`
  - Go to Step 2, then stop
- Values are accessed by a key that is not a part of the object
  - Use a `Map`.
- It doesn't matter. Values are always accessed "in bulk", by traversing the collection and doing something with each value

2) Determine the element types or key/value types
- For a `List` or `Set`, a single type
- For a `Map`, the key type and the value type

Steps to Choosing a Collection

3) Determine whether element or key order matters

- Elements or keys must be sorted
  - Use a `TreeSet` or `TreeMap`. Go to Step 6
- Elements must be in the same order in which they were inserted
  - Your choice is now narrowed down to a `LinkedList` or an `ArrayList`
- It doesn’t matter
  - If you chose a map in Step 1, use a `HashMap` and go to Step 5

Steps to Choosing a Collection

4) For a collection, determine which operations must be fast

- Finding elements must be fast
  - Use a `HashSet` and go to Step 5
- Adding and removing elements at the beginning or the middle must be fast
  - Use a `LinkedList`
- You only insert at the end, or you collect so few elements that you aren't concerned about speed
  - Use an `ArrayList`.

Steps to Choosing a Collection

5) For hash sets and maps, decide if you need to implement the `equals` and `hashCode` methods

- If your elements do not support them, you must implement them yourself.

6) If you use a tree, decide whether to supply a comparator

- If your element class does not provide it, implement the Comparable interface for your element class

Special Topic: Hash Functions

- Hashing can be used to find elements in a set data structure quickly, without making a linear search through all elements.
- A hashCode method computes and returns an integer value: the hash code.
  - Should be likely to yield different hash codes
  - Because hashing is so important, the Object class has a hashCode method that computes the hash code of any object x.

```
int h = x.hashCode();
```

Computing Hash Codes

- To put objects of a given class into a `HashSet` or use the objects as keys in a `HashMap`, the class should override the default `hashCode` method.
- A good `hashCode` method should work such that different objects are likely to have different hash codes.
  - It should also be efficient
  - A simple example for a String might be:

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

Computing Hash Codes

- But `Strings` that are permutations of another (such as "eat" and "tea") would all have the same hash code
- Better:
  - From the Java Library!

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

Sample Strings and HashCodes

- The `String` class implements a good example of a `hashCode` method
- It is possible for two or more distinct objects to have the same hash code: This is called a **collision**
  - A `hashCode` function should minimizes collisions

Table 6 Sample Strings and Their Hash Codes

String	Hash Code
"eat"	100184
"tea"	114704
"Juliet"	–2065036585
"Ugh"	84982
"VII"	84982

Computing Object Hash Codes

- You should have a good hashCode method for your own objects to store them efficiently
- Override hashCode methods in your own classes by combining the hash codes for the instance variables

```
public int hashCode()
{
   int h1 = name.hashCode();
   int h2 = new Double(area).hashCode();
. . .
```

- Then combine the hash codes using a prime-number hash multiplier:

```
   final int HASH_MULTIPLIER = 29;
   int h = HASH_MULTIPLIER * h1 + h2;
   return h;
}
```

hashCode and equals methods

- hashCode methods should be *compatible* with equals methods
  - If two objects are equal, their hashCodes should match
  - a hashCode method should use **all** instance variables
  - The hashCode method of the Object class uses the memory location of the object, not the contents

`hashCode` and `equals` methods

- Do not mix Object class `hashCode` or `equals` methods with your own:
  - Use an existing class such as String. Its `hashCode` and `equals` methods have already been implemented to work correctly.
  - Implement both `hashCode` and `equals`.
    - Derive the hash code from the instance variables that the `equals` method compares, so that equal objects have the same hash code
  - Implement neither `hashCode` nor `equals`. Then only identical objects are considered to be equal

15.5 Stacks, Queues and Priority Queues

- Queues and Stacks are specialized lists
  - Only allow adding and removing from the ends

	Insert At	Remove At	Operation
Stack	Start(top)	Start(top)	List in, first out (LIFO)
Queue	End (tail)	Start (head)	First in, first out (FIFO)
Priority Queue	By Priority	Highest Priority (Lowest #)	Prioritized list of tasks

Stacks, Queues and Priority Queues

- Stacks are used for undo features (most recent first)

- Queues are like lines at the bank or store

- Priority Queues remove lowest number first

Working with Stacks

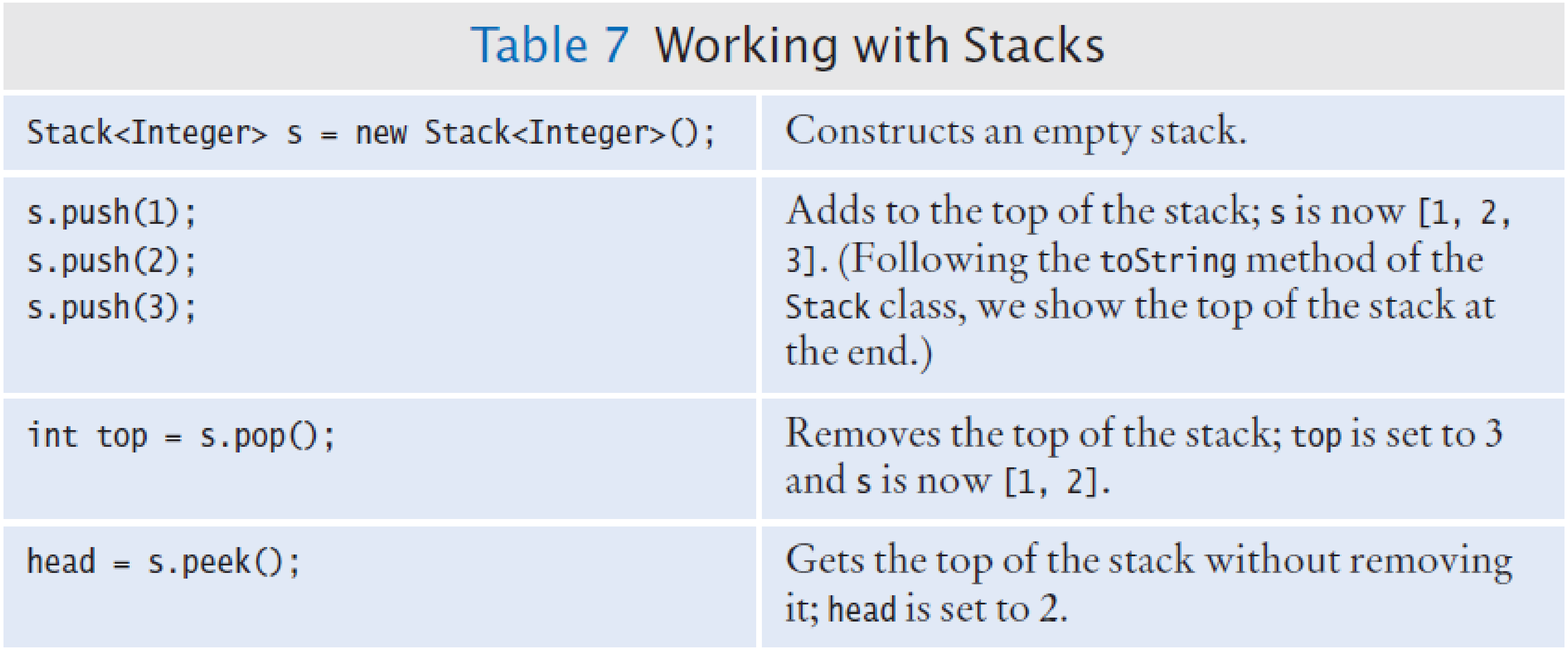


Table 7 Working with Stacks

`Stack<Integer> s = new Stack<Integer>();`	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.

Stack Example

- The Java library provides a `Stack` class that implements the abstract stack type's `push` and `pop` operations.
  - The Stack is not technically part of the Collections framework, but uses generic type parameters

```
Stack<String> s = new Stack<String>();
s.push("A");
s.push("B");
s.push("C");
// The following loop prints C, B, and A
while (s.size() > 0)
{
  System.out.println(s.pop());
}
```

The `stack` class provides a `size` method

Queues and Priority Queues

Table 8 Working with Queues

`Queue<Integer> q = new LinkedList<Integer>();`	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.

Table 9 Working with Priority Queues

`PriorityQueue<Integer> q =`
`   new PriorityQueue<Integer>();`
	This priority queue holds integers. 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 lowest priority item: `first` is set to 1, `second` to 2.

`int next = q.peek();`	Gets the smallest value in the priority queue without removing it.

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
  - It is NOT a FIFO Queue

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

  - Lowest value priority (1) will be removed first

```
WorkOrder next = q.remove();  // removes “Fix broken sink”
```

15.6 Stack and Queue Applications

- Balancing Parenthesis
  - Section 2.5, showed how to balance parenthesis by adding 1 for each left (and subtracting for each right)

```
-(b * b - (4 * a * c ) ) / (2 * a)
 1        2            1 0   1     0
```

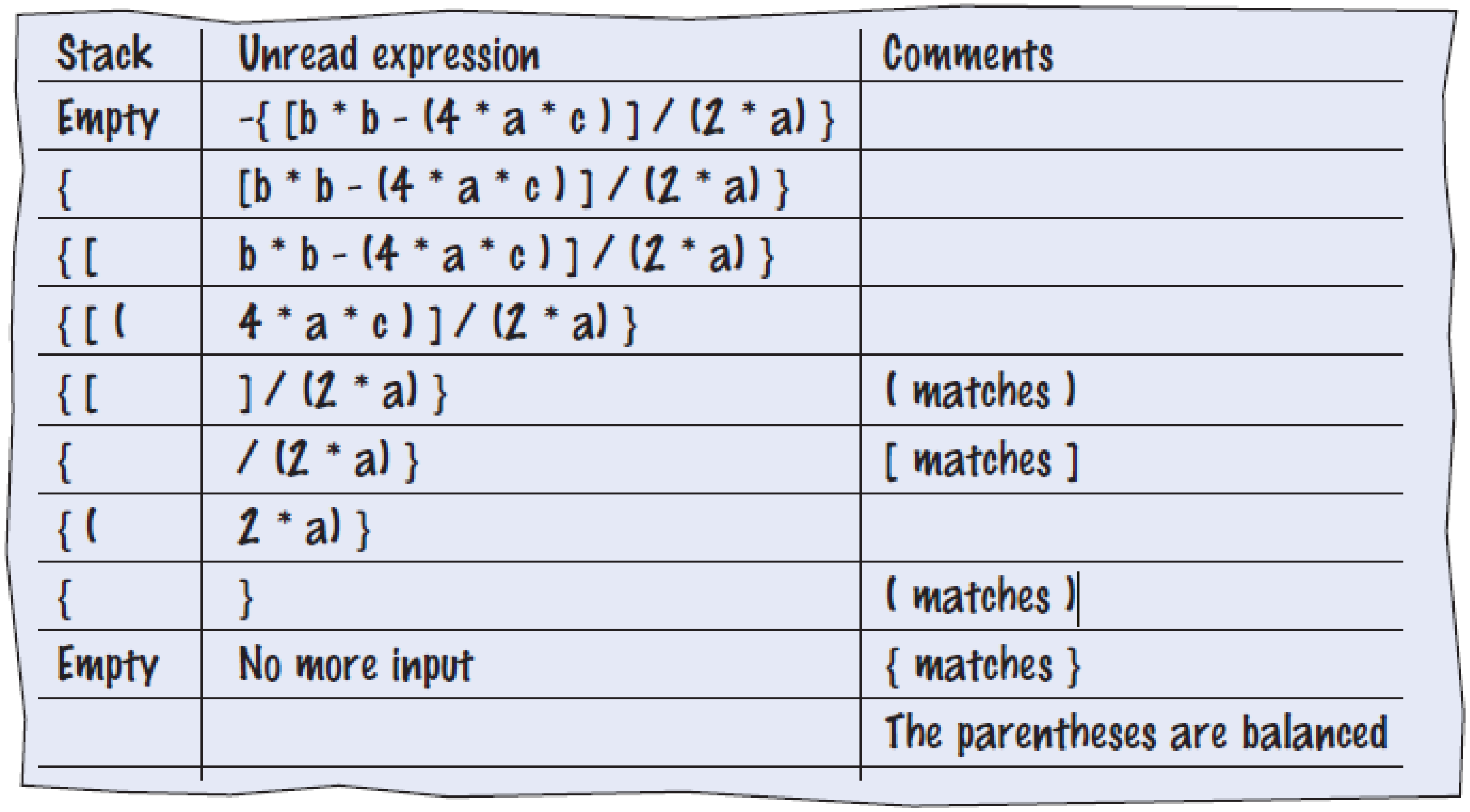
  - A stack can be used to keep track of 'depth':

```
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.
```

Using a Stack (Example)

- Here is a walkthrough of the sample expression
  - We will use the mathematical version (three types of parenthesis)

$$-\{[b \cdot b - (4 \cdot a \cdot c)] / (2 \cdot a)\}$$



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

Reverse Polish Expressions

- The first handheld calculator used a notation that was easily implemented with a stack: Reverse Polish
  - No parenthesis required if you…
    - Input both operands first, then the operator:

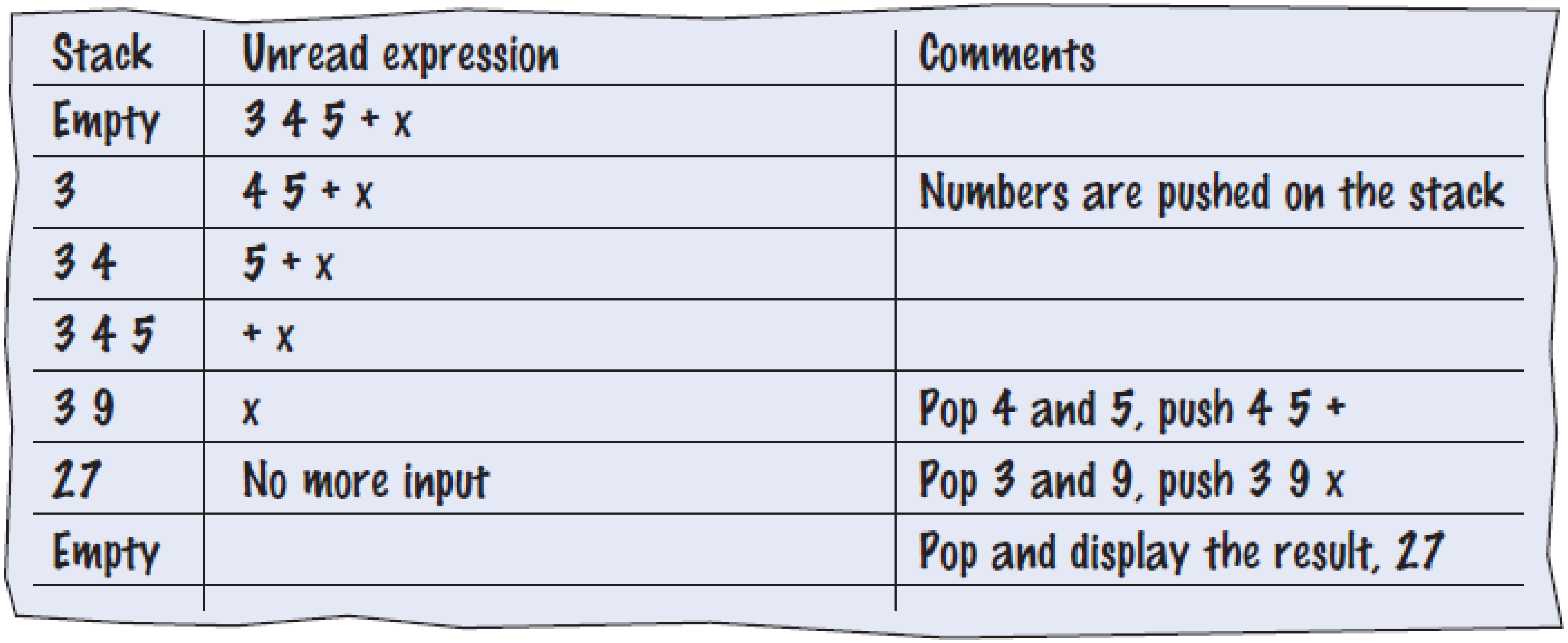
Algebra	Reverse Polish
(3 + 4) x 5	3 4 + 5 x
(3 + 4) x (5 + 6)	3 4 + 5 6 + x

Reverse Polish Expressions

```
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.
```

Reverse Polish Calculator

- Walkthrough with `3 4 5 + x`



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

Calculator.java (1)

```java
import java.util.Scanner;
import java.util.Stack;

/**
   This calculator uses the reverse polish notation.
*/
public class Calculator
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      Stack<Integer> results = new Stack<Integer>();
      System.out.println("Enter one number or operator per line, Q to quit. ");
      boolean done = false;
      while (!done)
      {
         String input = in.nextLine();

         // If the command is an operator, pop the arguments and push the result

         if (input.equals("+"))
         {
            results.push(results.pop() + results.pop());
         }
         else if (input.equals("-"))
         {
```

Calculator.java (2)

Program Run

```
Enter one number or operator per line, Q to quit.
3
[3]
4
[3, 4]
+
[7]
5
[7, 5]
*
[35]
```

```java
            Integer arg2 = results.pop();
            results.push(results.pop() - arg2);
         }
         else if (input.equals("*") || input.equals("x"))
         {
            results.push(results.pop() * results.pop());
         }
         else if (input.equals("/"))
         {
            Integer arg2 = results.pop();
            results.push(results.pop() / arg2);
         }
         else if (input.equals("Q") || input.equals("q"))
         {
            done = true;
         }
         else
         {
            // Not an operator--push the input value

            results.push(Integer.parseInt(input));
         }
         System.out.println(results);
      }
   }
}
```

Evaluating Algebraic Expressions

- Can be done with two stacks:
  1) Numbers
  2) Operators
- First Example: `3 + 4`

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

Expression Example 2

- Second Example: `3 x 4 + 5`

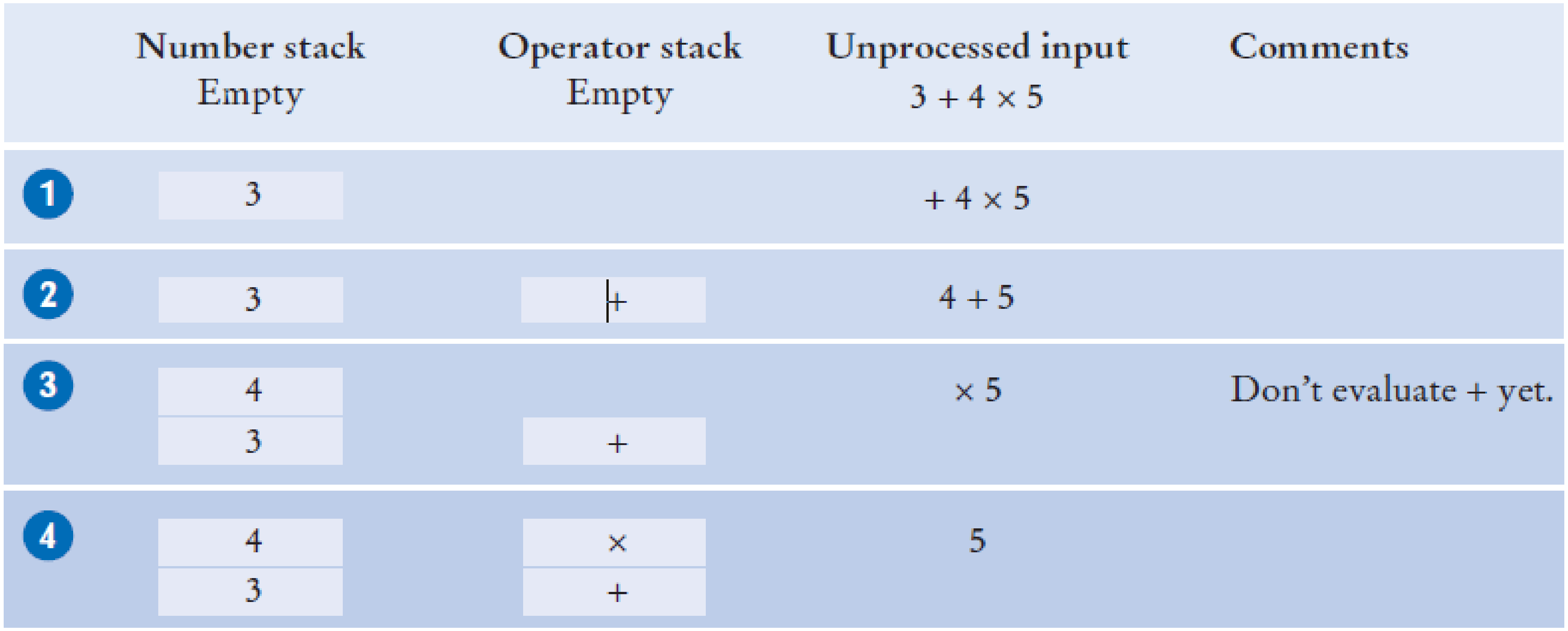
	Number stack	Operator stack	Unprocessed input	Comments
	Empty	Empty	3 × 4 + 5	
1	3		× 4 + 5	
2	3	×	4 + 5	
3	4, 3	×	+ 5	Evaluate × before +.

  - Must use precedence (multiply before adding)

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

Precedence and Expressions (1)

- Third Example: 3 + 4 x 5

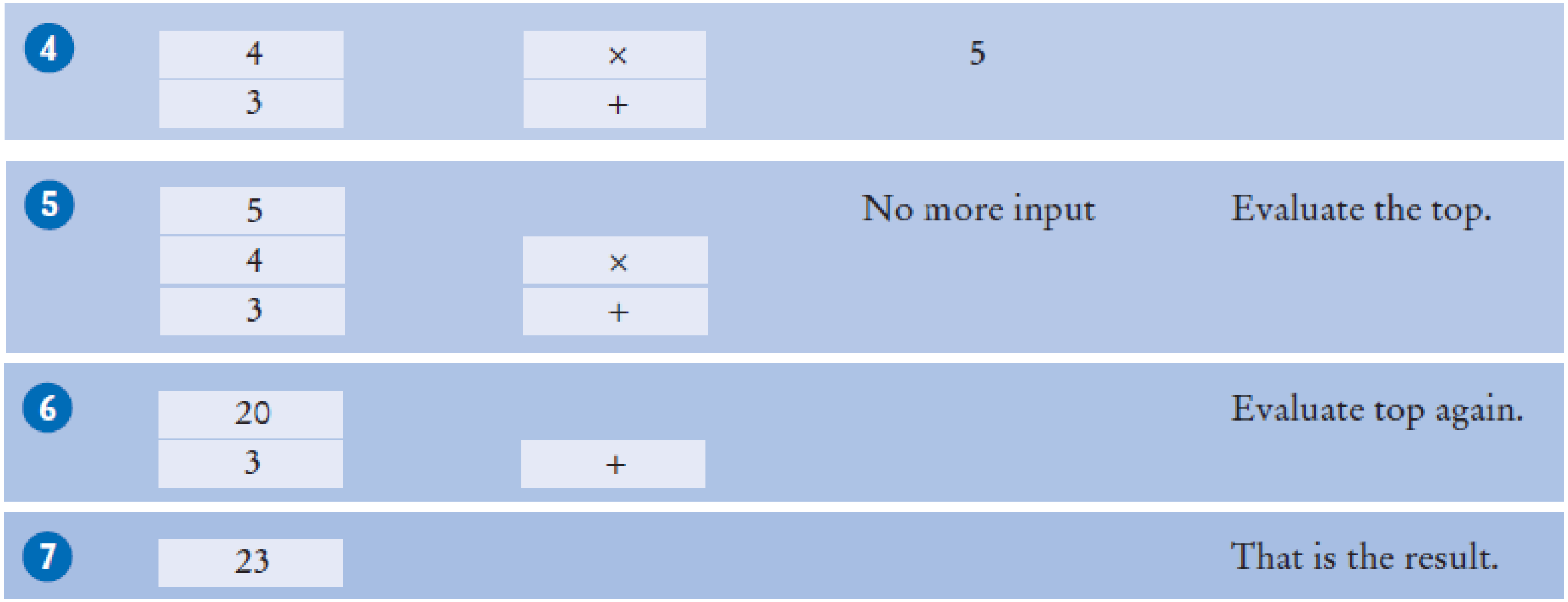


	Number stack	Operator stack	Unprocessed input	Comments
	Empty	Empty	3 + 4 × 5	
1	3		+ 4 × 5	
2	3	+	4 + 5	
3	4 3	+	× 5	Don't evaluate + yet.
4	4 3	× +	5	

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

Precedence and Expressions (2)

- Third Example: 3 + 4 x 5

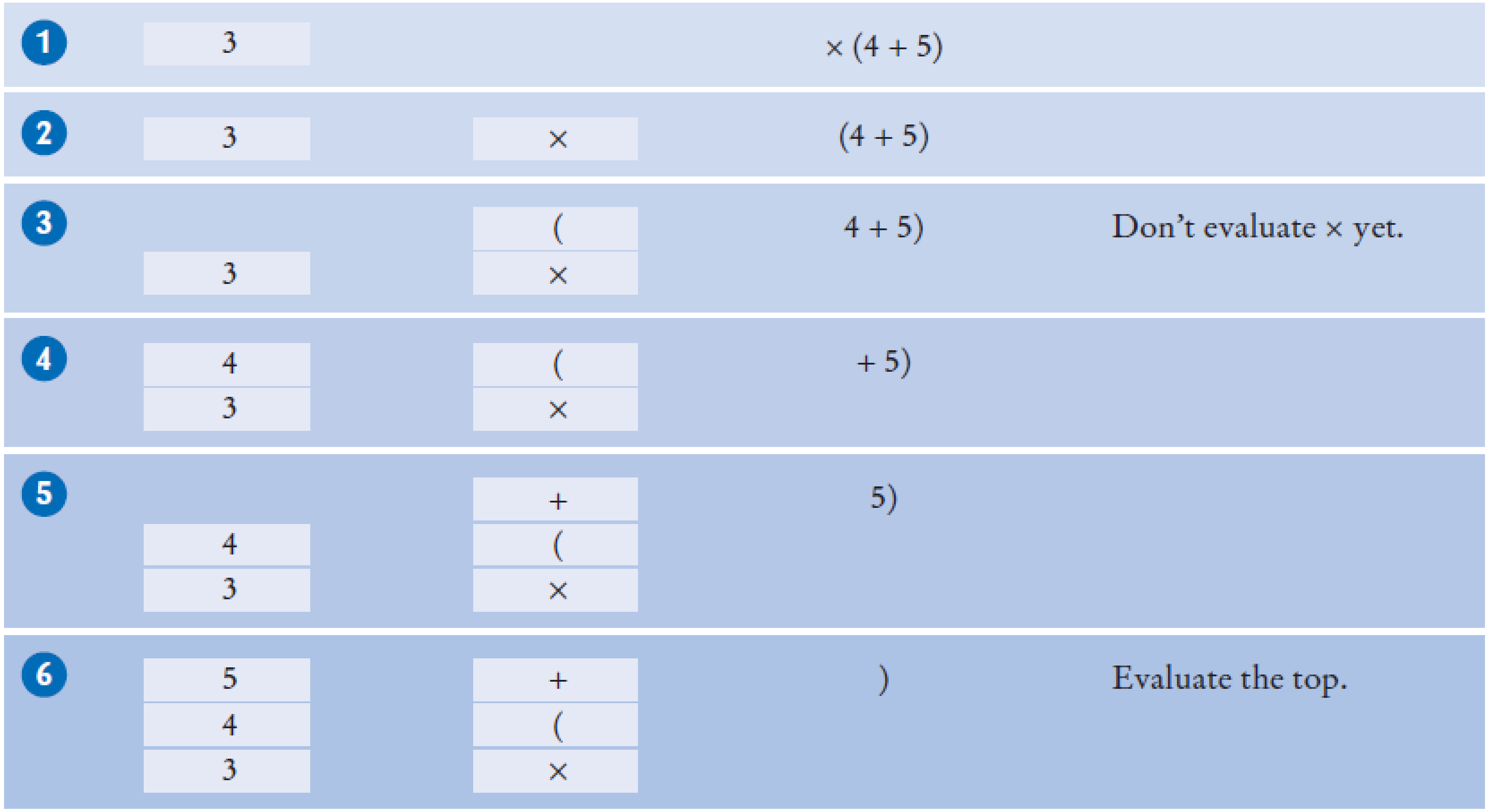


4	4 3	× +	5	
5	5 4 3	× +	No more input	Evaluate the top.
6	20 3	+		Evaluate top again.
7	23			That is the result.

- Evaluate top 2 numbers with top operator
- Store result on top of stack
- Evaluate until operator stack is empty

Expressions with Parenthesis (1)

- Fourth Example: 3 x (4 + 5)

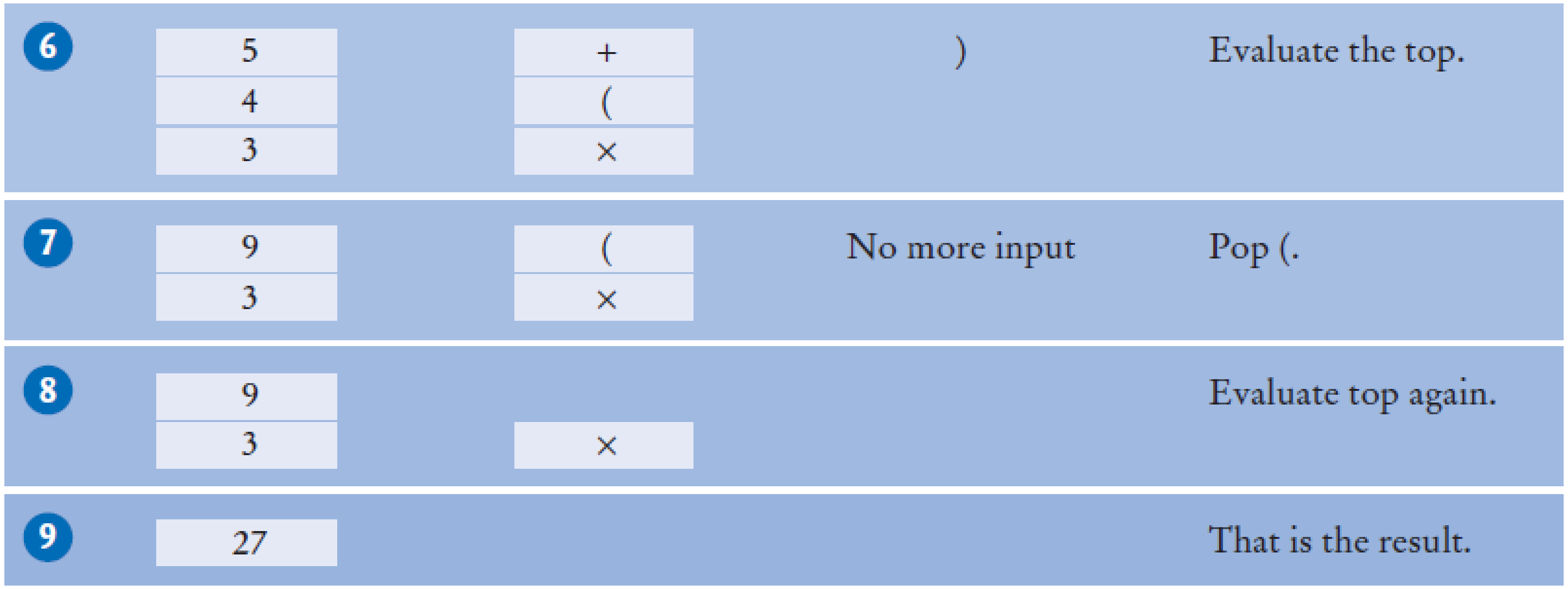


1	3		× (4 + 5)	
2	3	×	(4 + 5)	
3	3	(×	4 + 5)	Don’t evaluate × yet.
4	4 3	(×	+ 5)	
5	4 3	+ (×	5)	
6	5 4 3	+ (×	)	Evaluate the top.

  - If (, don’t evaluate. If), evaluate

Expressions with Parenthesis (2)

- Fourth Example: 3 x (4 + 5)



6	5	+	)	Evaluate the top.
	4	(		
	3	×		
7	9	(	No more input	Pop (.
	3	×		
8	9			Evaluate top again.
	3	×		
9	27			That is the result.

  - Don’t put) on stack – evaluate now
  - Ignore (

Precedence 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.
```

<u>Evaluate the Top:</u>

Pop two numbers off the number stack.

Pop an operator off the operator stack.

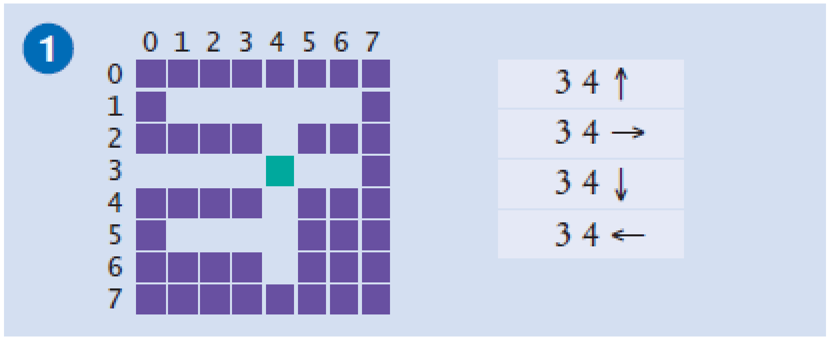
Combine the numbers with that operator.

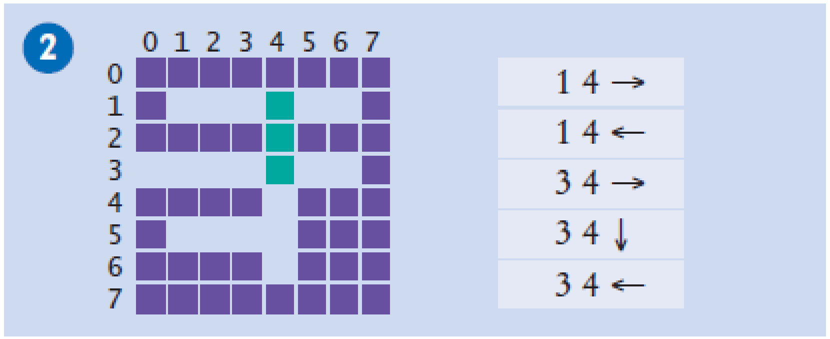
Push the result on the number stack.

Backtracking (1)

- Uses a stack to solve a maze
- Stack current location, arrow for each possible path

1. We pop off the topmost one, traveling north from (3, 4). Following this path leads to position (1, 4).
2. We now push two choices on the stack, going west or east.





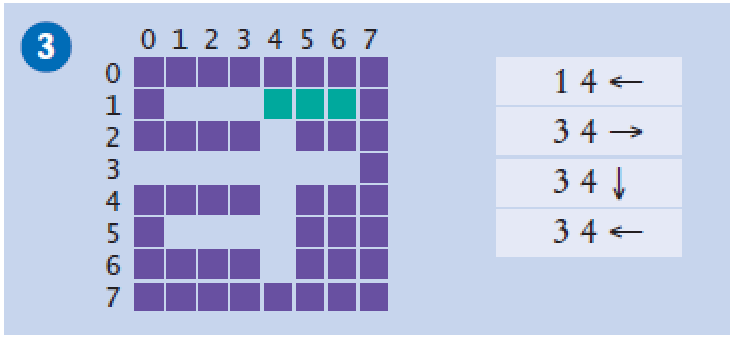
Backtracking (2)

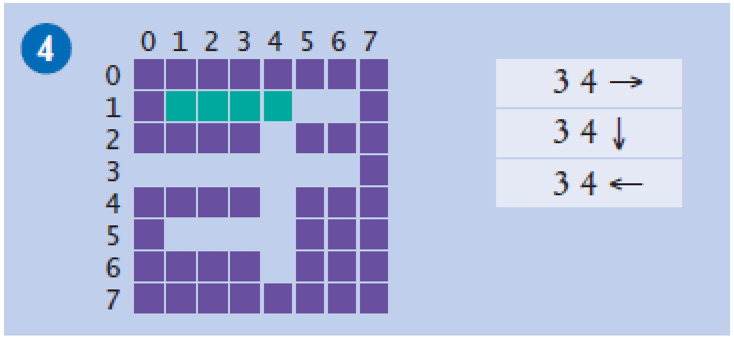
3. Pop off (1, 4) east. It is a dead end.

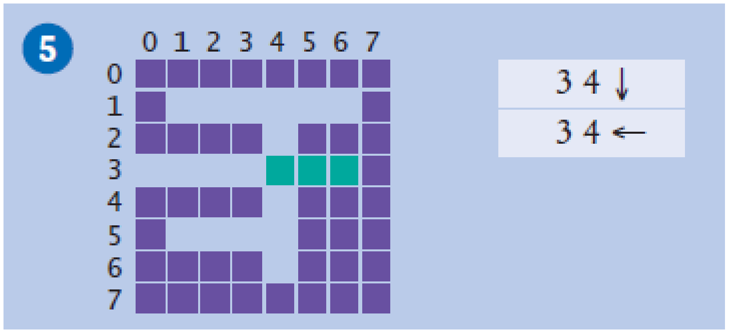
4. Pop off (1, 4) west. It is a dead end.

5. Now we pop off the path from (3, 4) going east. That too is a dead end.

This leaves us with (3, 4) south and (3, 4) west to try

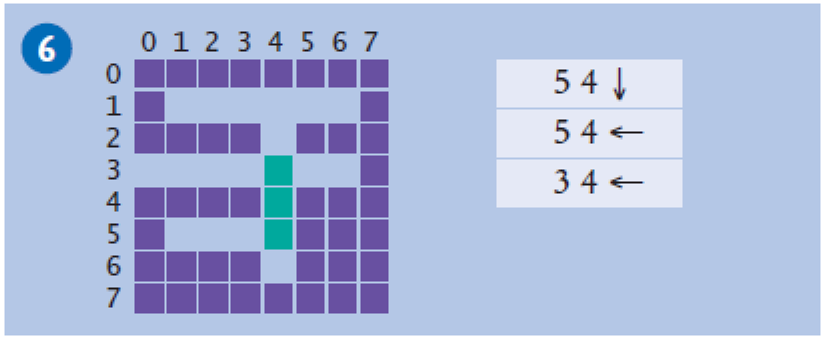


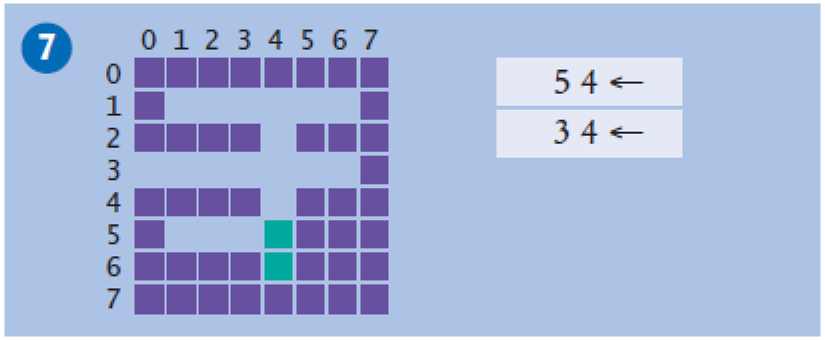


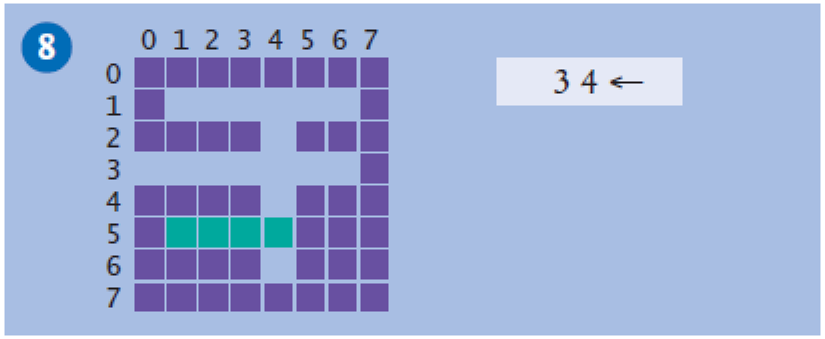


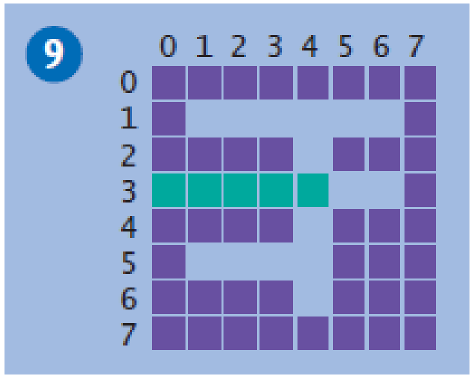
Backtracking (3)

6. Next is the path from (3, 4) going south. At (5, 4), it comes to an intersection. Both choices are pushed on the stack.
7. (5, 4) south is a dead end.
8. (5, 4) west is a dead end.
9. Finally, the path from (3, 4) going west leads to an exit







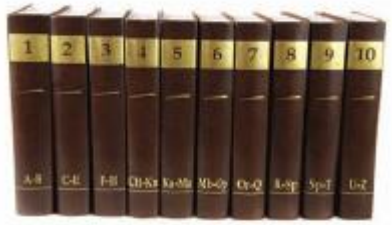


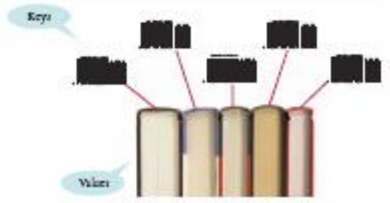
Maze Solving Pseudocode

```
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.
```

Summary: Collections

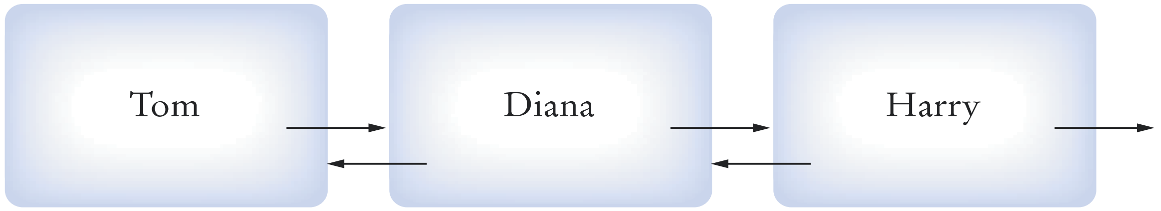
- A collection groups together elements and allows them to be retrieved later
  - A **list** is a collection that remembers the order of its elements
  - A **set** is an unordered collection of unique elements
  - A **map** keeps associations between key and value objects





Summary: Linked Lists

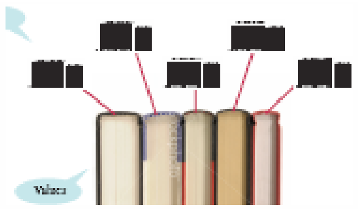
- A linked list consists of a number of nodes, each of which has a reference to the next node
  - Adding and removing elements in the middle of a linked list is efficient
  - Visiting the elements of a linked list in sequential order is efficient, but random access is not
  - You use a list iterator to access elements of a linked list



Summary: Choosing a Set

- The `HashSet` and `TreeSet` classes both implement the `Set` interface.
- Set implementations arrange the elements so that they can locate them quickly.
- You can form hash sets holding objects of type `String`, `Integer`, `Double`, `Point`, `Rectangle`, or `Color`.
- You can form tree sets for any class that implements the `Comparable` interface, such as `String` or `Integer`.
- Sets don't have duplicates. Adding a duplicate of an element that is already present is silently ignored.
- A set iterator visits the elements in the order in which the set implementation keeps them.
- You cannot add an element to a set at an iterator position.

Summary: Maps



- Maps associate keys with values
  - The `HashMap` and `TreeMap` classes both implement the `Map` interface
  - To find all keys and values in a `Map`, iterate through the key set and find the values that correspond to the keys
  - A hash function computes an integer value from an object.
  - A good hash function minimizes **collisions**—identical hash codes for different objects.
  - Override `hashCode` methods in your own classes by combining the hash codes for the instance variables.
  - A class's `hashCode` method must be compatible with its `equals` method.

Summary: Stacks and Queues

- A stack is a collection of elements with "last-in, first-out" retrieval.

- A queue is a collection of elements with "first-in, first-out" retrieval.
- When removing an element from a priority queue, the element with the most urgent priority is retrieved.

Summary: Problem Solving

- A stack can be used to check whether parentheses in an expression are balanced.
- Use a stack to evaluate expressions in reverse Polish notation.
- Using two stacks, you can evaluate expressions in standard algebraic notation.
- Use a stack to remember choices you haven’t yet made so that you can backtrack to them.