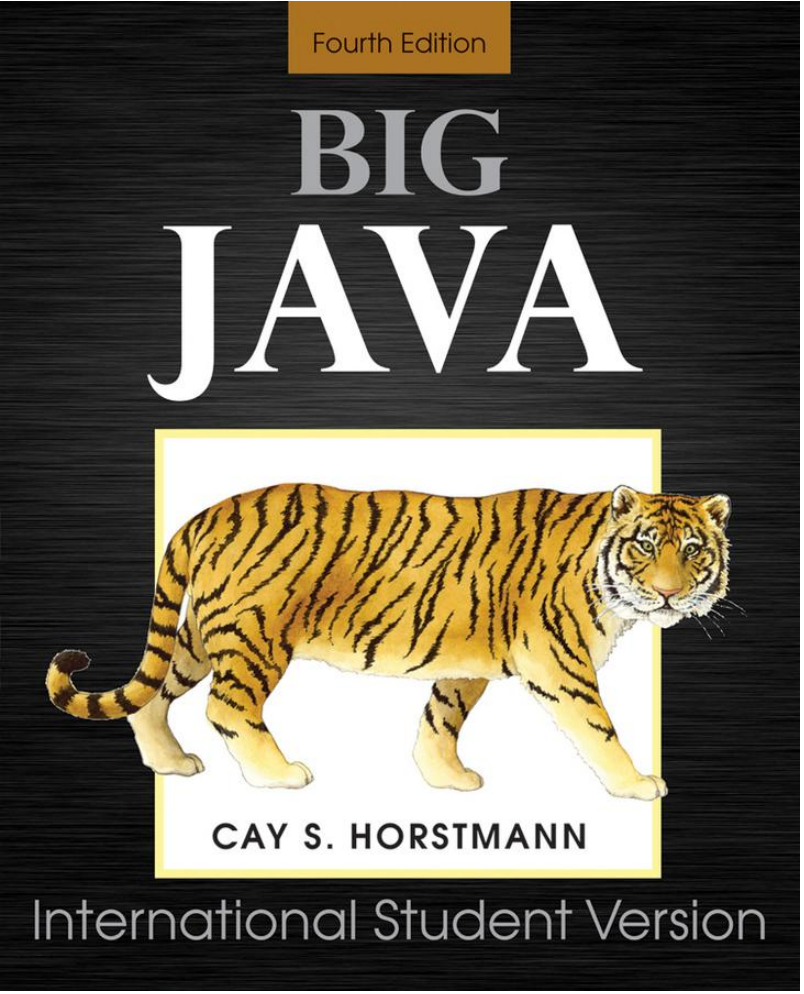


Chapter 6 – Arrays and Array Lists

Chapter Goals

- To become familiar with using arrays and array lists
- To learn about wrapper classes, auto-boxing and the generalized for loop
- To study common array algorithms
- To learn how to use two-dimensional arrays
- To understand when to choose array lists and arrays in your programs
- To implement partially filled arrays
- To understand the concept of regression testing

Arrays

- Array: Sequence of values of the same type
- Construct array:

```
new double[10]
```

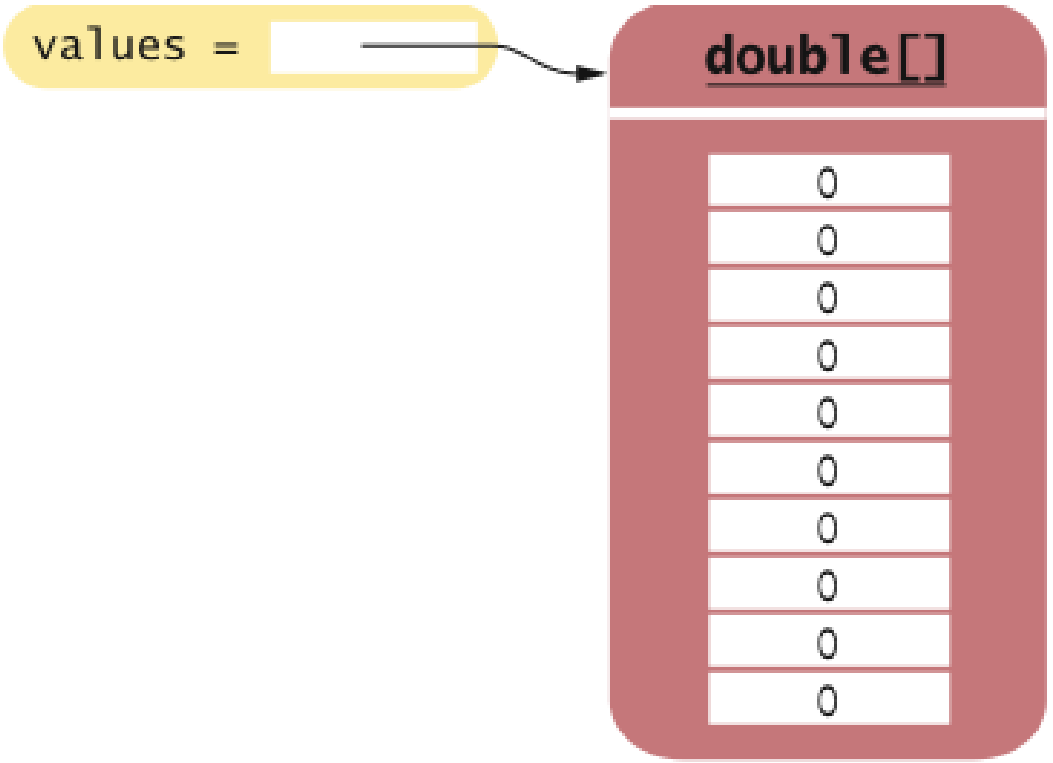
- Store in variable of type `double[]`:

```
double[] data = new double[10];
```

- When array is created, all values are initialized depending on array type:
  - *Numbers:* `0`
  - *Boolean:* `false`
  - *Object References:* `null`

Arrays

Figure 1
An Array Reference and an Array



Arrays

Use `[]` to access an element:

```
values[2] = 29.95;
```

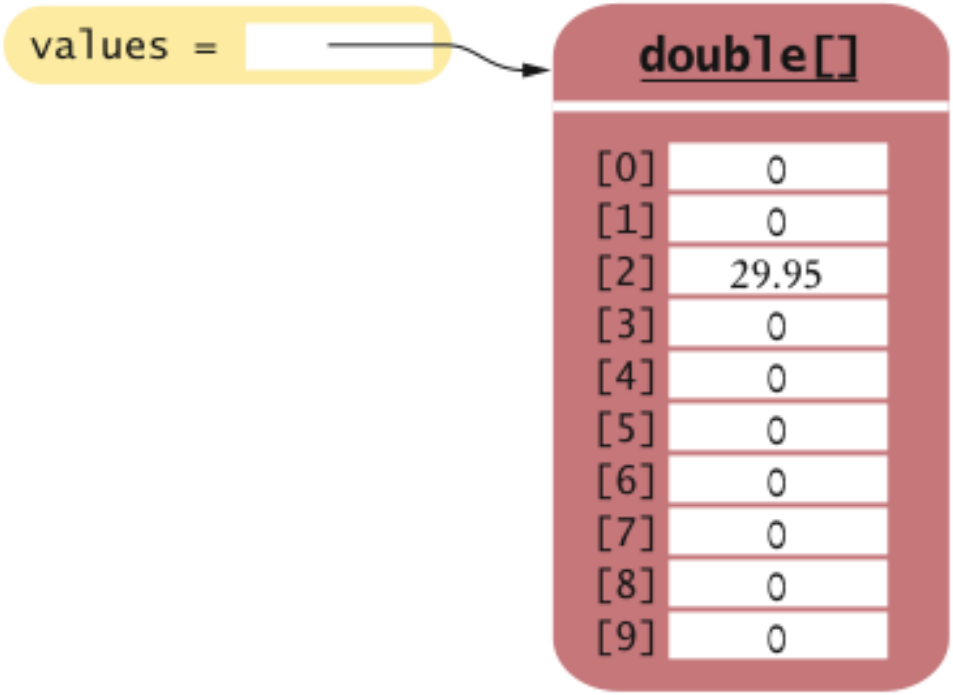


Figure 2
Modifying an Array Element

Arrays

- Using the value stored:

```
System.out.println("The value of this data item is "
   + values[2]);
```

- Get array length as `values.length` (Not a method!)
- Index values range from `0` to `length - 1`
- Accessing a nonexistent element results in a **bounds error**:

```
double[] values = new double[10];
values[10] = 29.95; // ERROR
```

- Limitation: Arrays have fixed length

Declaring Arrays

Table 1 Declaring Arrays

`int[] numbers = new int[10];`	An array of ten integers. All elements are initialized with zero.
`final int NUMBERS_LENGTH = 10;` `int[] numbers = new int[NUMBERS_LENGTH];`	It is a good idea to use a named constant instead of a "magic number".
`int valuesLength = in.nextInt();` `double[] values = new double[valuesLength];`	The length need not be a constant.
`int[] squares = { 0, 1, 4, 9, 16 };`	An array of five integers, with initial values.
`String[] names = new String[3];`	An array of three string references, all initially `null`.
`String[] friends = { "Emily", "Bob", "Cindy" };`	Another array of three strings.
`double[] values = new int[10]`	**Error:** You cannot initialize a `double[]` variable with an array of type `int[]`.

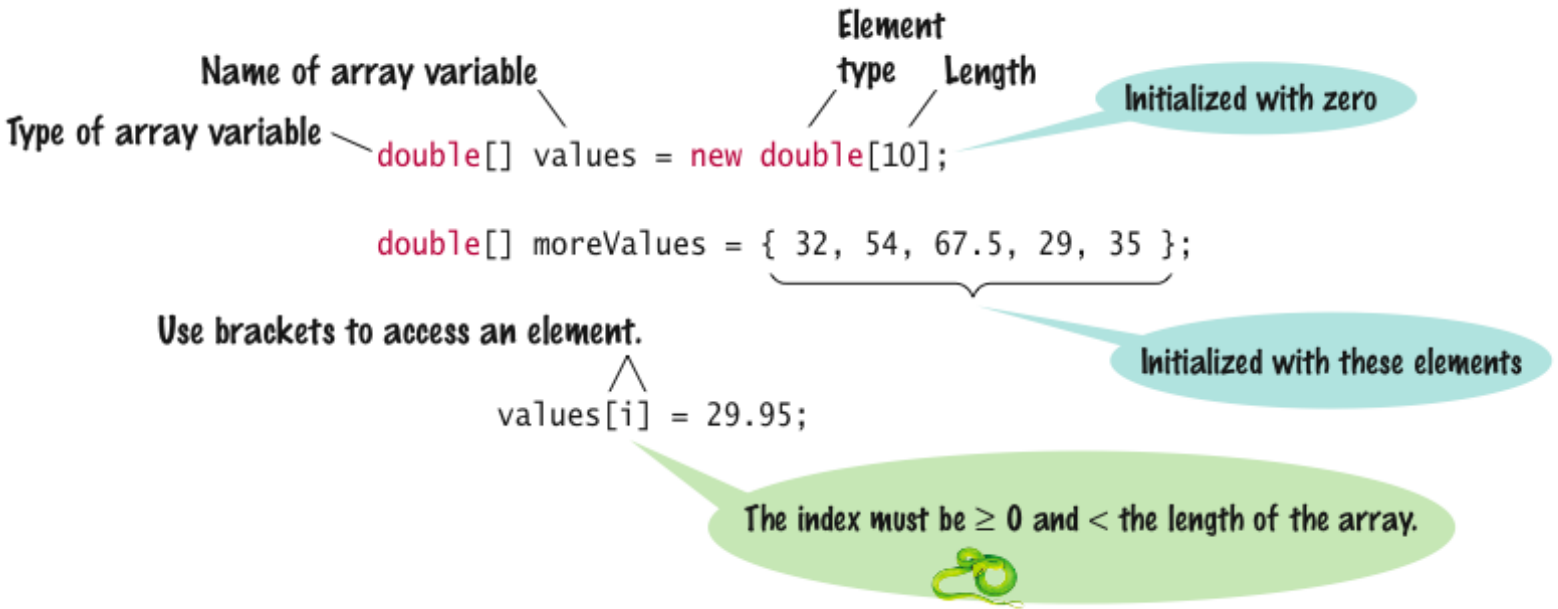
Syntax 6.1 Arrays

Syntax

To construct an array: `new typeName[length]`

To access an element: `arrayReference[index]`

Example



Self Check 6.1

What elements does the data array contain after the following statements?

```
double[] values = new double[10];
for (int i = 0; i < values.length; i++)
   values[i] = i * i;
```

Answer: 0, 1, 4, 9, 16, 25, 36, 49, 64, 81, but not 100

Self Check 6.2

What do the following program segments print? Or, if there is an error, describe the error and specify whether it is detected at compile-time or at run-time.

```
a) double[] a = new double[10];
   System.out.println(a[0]);

b) double[] b = new double[10];
   System.out.println(b[10]);

c) double[] c;
   System.out.println(c[0]);
```

Answer:

a) 0

b) a run-time error: array index out of bounds

c) a compile-time error: c is not initialized

Make Parallel Arrays into Arrays of Objects

```
// Don't do this
int[] accountNumbers;
double[] balances;
```

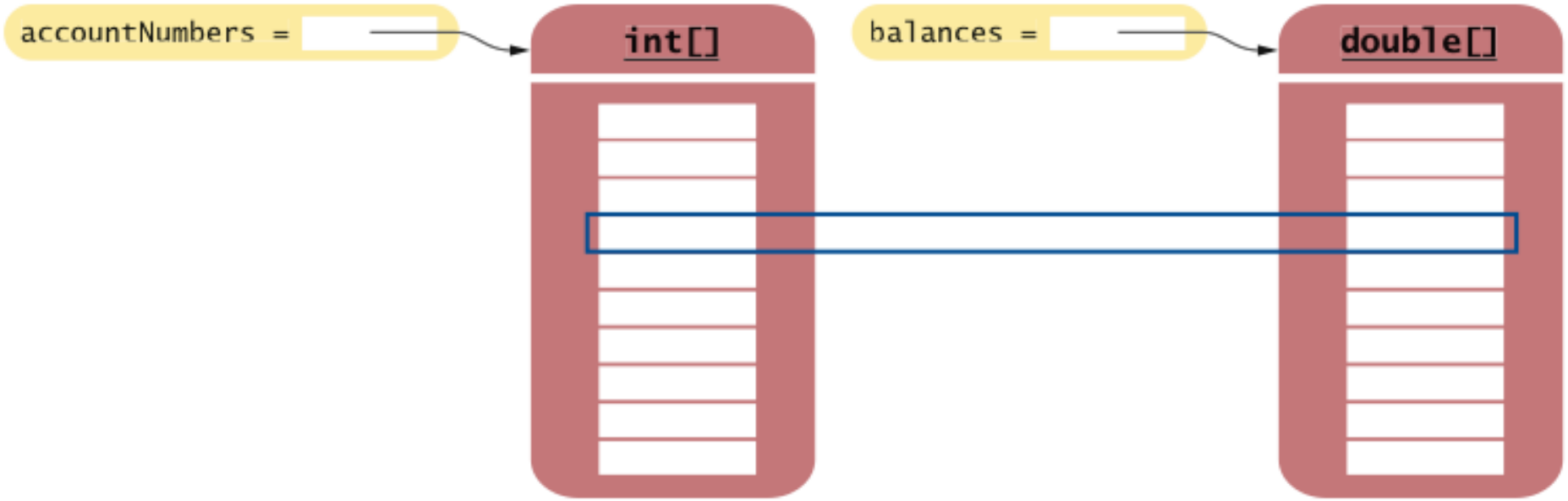


Figure 3 Avoid Parallel Arrays

Make Parallel Arrays into Arrays of Objects

Avoid parallel arrays by changing them into arrays of objects:

```
BankAccount[] accounts;
```

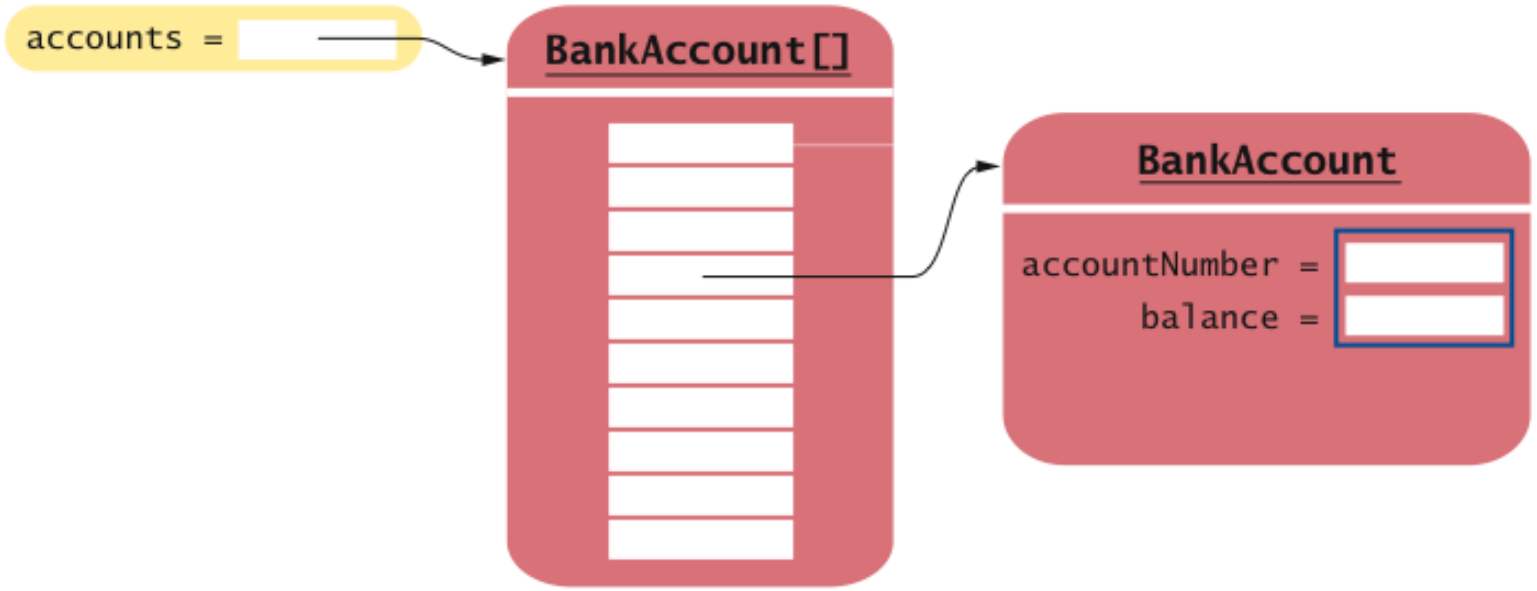
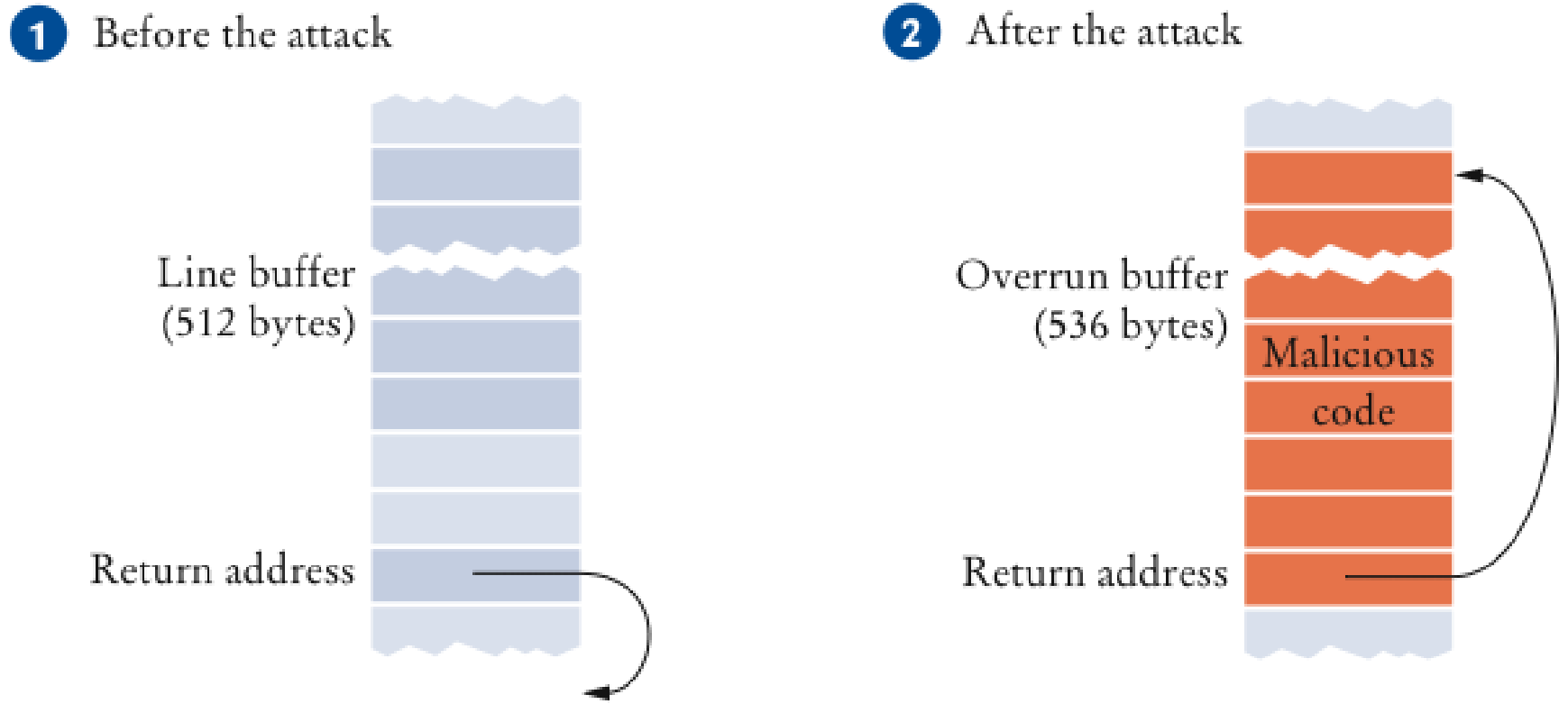


Figure 4 Reorganizing Parallel Arrays into an Array of Objects

An Early Internet Worm



A "Buffer Overrun" Attack

Array Lists

- `ArrayList` class manages a sequence of objects
- Can grow and shrink as needed
- `ArrayList` class supplies methods for many common tasks, such as inserting and removing elements
- `ArrayList` is a **generic class**:

  `ArrayList<T>`

  collects objects of **type parameter** `T`:

```
ArrayList<String> names = new ArrayList<String>();
names.add("Emily");
names.add("Bob");
names.add("Cindy");
```

- `size` method yields number of elements

Adding Elements

To add an object to the end of the array list, use the `add` method:

```
names.add("Emily");
names.add("Bob");    1
names.add("Cindy");  2
```

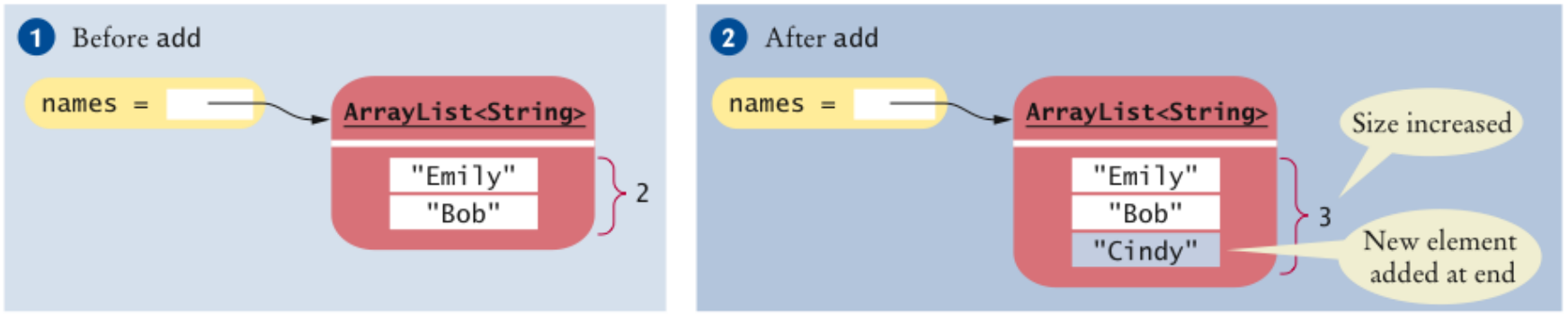


Figure 5 Adding an Element with add

Retrieving Array List Elements

- To obtain the value an element at an index, use the `get` method
- Index starts at 0
-
```
String name = names.get(2);
// gets the third element of the array list
```
- Bounds error if index is out of range
- Most common bounds error:

```
int i = names.size();
name = names.get(i); // Error
// legal index values are 0 ... i-1
```

Setting Elements

- To set an element to a new value, use the `set` method:

```
names.set(2, "Carolyn");
```

Removing Elements

- To remove an element at an index, use the `remove` method:

```
names.remove(1);
```

Adding and Removing Elements

```
names.add("Emily");
names.add("Bob");
names.add("Cindy");
names.set(2, "Carolyn");
names.add(1, "Ann");
names.remove(1);
```

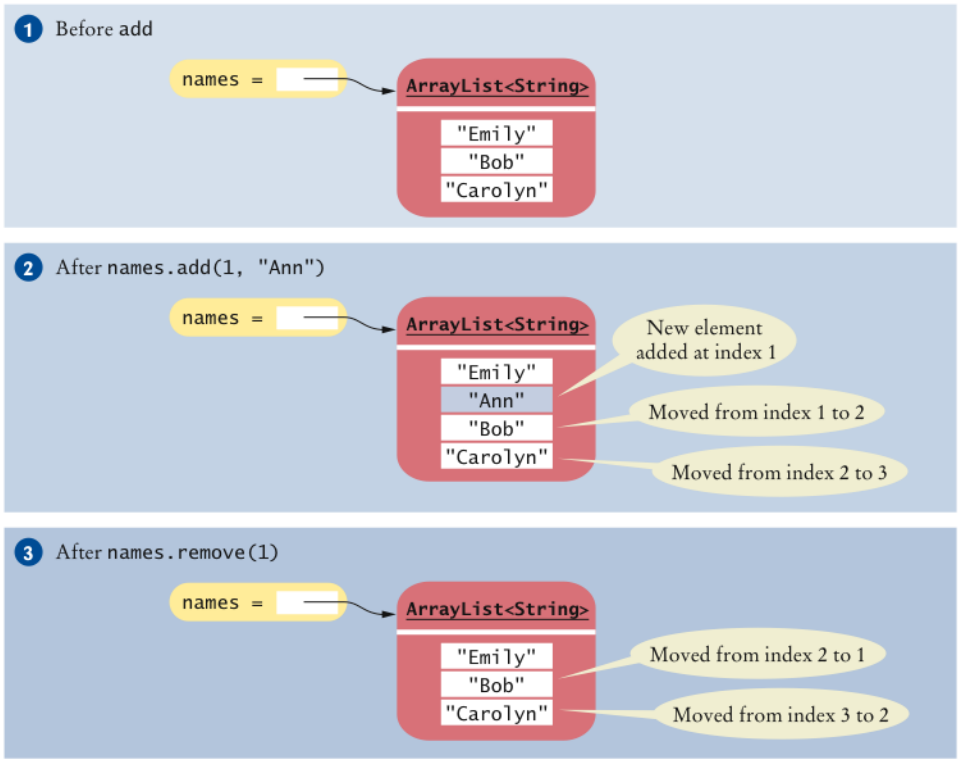


Figure 6 Adding and Removing Elements in the Middle of an Array List

Working with Array Lists

`ArrayList<String> names = new ArrayList<String>();`	Constructs an empty array list that can hold strings.
`names.add("Ann");` `names.add("Cindy");`	Adds elements to the end.
`System.out.println(names);`	Prints `[Ann, Cindy]`.
`names.add(1, "Bob");`	Inserts an element at index 1. `names` is now `[Ann, Bob, Cindy]`.
`names.remove(0);`	Removes the element at index 0. `names` is now `[Bob, Cindy]`.
`names.set(0, "Bill");`	Replaces an element with a different value. `names` is now `[Bill, Cindy]`.

Working with Array Lists (cont.)

`String name = names.get(i);`	Gets an element.
`String last =` `  names.get(names.size() - 1);`	Gets the last element.

`ArrayList<Integer> squares =`
`  new ArrayList<Integer>();`
`for (int i = 0; i < 10; i++)`
`{`
`  squares.add(i * i);`
`}`
	Constructs an array list holding the first ten squares.

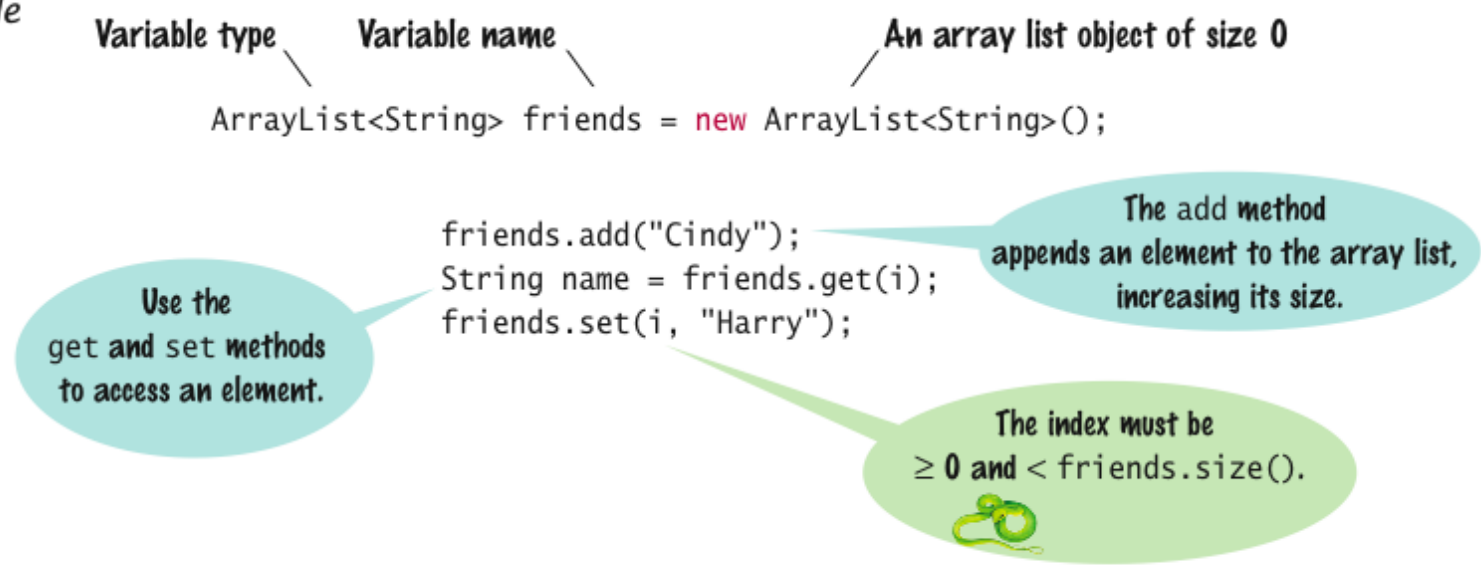
Syntax 6.2 Array Lists

Syntax

To construct an array list: `new ArrayList<typeName>()`

To access an element:
arraylistReference`.get(index)`
arraylistReference`.set(index, value)`

Example



ch06/arraylist/ArrayListTester.java

```
1  import java.util.ArrayList;
2
3  /**
4     This program tests the ArrayList class.
5  */
6  public class ArrayListTester
7  {
8     public static void main(String[] args)
9     {
10       ArrayList<BankAccount> accounts = new ArrayList<BankAccount>();
11       accounts.add(new BankAccount(1001));
12       accounts.add(new BankAccount(1015));
13       accounts.add(new BankAccount(1729));
14       accounts.add(1, new BankAccount(1008));
15       accounts.remove(0);
16
17       System.out.println("Size: " + accounts.size());
18       System.out.println("Expected: 3");
19       BankAccount first = accounts.get(0);
20       System.out.println("First account number: "
21             + first.getAccountNumber());
22       System.out.println("Expected: 1008");
23       BankAccount last = accounts.get(accounts.size() - 1);
24       System.out.println("Last account number: "
25             + last.getAccountNumber());
26       System.out.println("Expected: 1729");
27    }
28 }
```

ch06/arraylist/BankAccount.java

```
1  /**
2     A bank account has a balance that can be changed by
3     deposits and withdrawals.
4  */
5  public class BankAccount
6  {
7     private int accountNumber;
8     private double balance;
9
10    /**
11       Constructs a bank account with a zero balance.
12       @param anAccountNumber the account number for this account
13    */
14    public BankAccount(int anAccountNumber)
15    {
16       accountNumber = anAccountNumber;
17       balance = 0;
18    }
19
```

Continued

ch06/arraylist/BankAccount.java (cont.)

```
20      /**
21         Constructs a bank account with a given balance
22         @param anAccountNumber the account number for this account
23         @param initialBalance the initial balance
24      */
25      public BankAccount(int anAccountNumber, double initialBalance)
26      {
27         accountNumber = anAccountNumber;
28         balance = initialBalance;
29      }
30
31      /**
32         Gets the account number of this bank account.
33         @return the account number
34      */
35      public int getAccountNumber()
36      {
37         return accountNumber;
38      }
39
```

Continued

ch06/arraylist/BankAccount.java (cont.)

```
40      /**
41         Deposits money into the bank account.
42         @param amount the amount to deposit
43      */
44      public void deposit(double amount)
45      {
46         double newBalance = balance + amount;
47         balance = newBalance;
48      }
49
50      /**
51         Withdraws money from the bank account.
52         @param amount the amount to withdraw
53      */
54      public void withdraw(double amount)
55      {
56         double newBalance = balance - amount;
57         balance = newBalance;
58      }
59
```

Continued

ch06/arraylist/BankAccount.java (cont.)

```
60      /**
61         Gets the current balance of the bank account.
62         @return the current balance
63      */
64      public double getBalance()
65      {
66         return balance;
67      }
68   }
```

Program Run:

```
Size: 3
Expected: 3
First account number: 1008
Expected: 1008
Last account number: 1729
Expected: 1729
```

Self Check 6.3

How do you construct an array of 10 strings? An array list of strings?

Answer:

```
new String[10];
new ArrayList<String>();
```

Self Check 6.4

What is the content of `names` after the following statements?

```
ArrayList<String> names = new ArrayList<String>();
names.add("A");
names.add(0, "B");
names.add("C");
names.remove(1);
```

Answer: `names` contains the strings `"B"` and `"C"` at positions 0 and 1

Wrapper Classes

- For each primitive type there is a **wrapper class** for storing values of that type:

```
Double d = new Double(29.95);
```

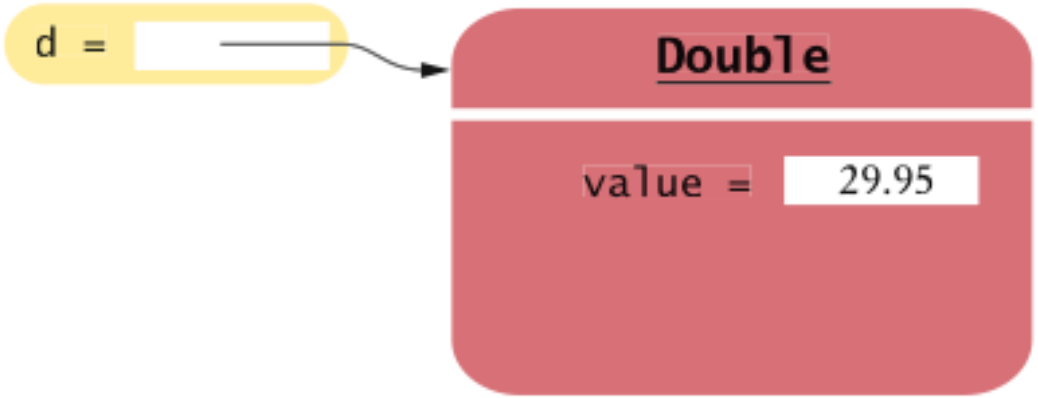


Figure 7 An Object of a Wrapper Class

- Wrapper objects can be used anywhere that objects are required instead of primitive type values:

```
ArrayList<Double> values= new ArrayList<Double>();
data.add(29.95);
double x = data.get(0);
```

Wrappers

There are wrapper classes for all eight primitive types:

Primitive Type	Wrapper Class
byte	Byte
boolean	Boolean
char	Character
double	Double
float	Float
int	Integer
long	Long
short	Short

Auto-boxing

- **Auto-boxing:** Automatic conversion between primitive types and the corresponding wrapper classes:

```
Double d = 29.95; // auto-boxing; same as
                  // Double d = new Double(29.95);
double x = d; // auto-unboxing; same as
              // double x = d.doubleValue();
```

- Auto-boxing even works inside arithmetic expressions:

```
d = d + 1;
```

Means:

- *auto-unbox* `d` *into a* `double`
- *add* `1`
- *auto-box the result into a new* `Double`
- *store a reference to the newly created wrapper object in* `d`

Auto-boxing and Array Lists

- To collect numbers in an array list, use the wrapper type as the type parameter, and then rely on auto-boxing:

```
ArrayList<Double> values = new ArrayList<Double>();
values.add(29.95);
double x = values.get(0);
```

- Storing wrapped numbers is quite inefficient
  - *Acceptable if you only collect a few numbers*
  - *Use arrays for long sequences of numbers or characters*

Self Check 6.5

What is the difference between the types `double` and `Double`?

Answer: `double` is one of the eight primitive types. `Double` is a class type.

Self Check 6.6

Suppose `values` is an `ArrayList<Double>` of size > 0. How do you increment the element with index 0?

Answer:

```
values.set(0, values.get(0) + 1);
```

The Enhanced `for` Loop

- Traverses all elements of a collection:

```
double[] values = ...;
double sum = 0;
for (double element : values)
{
   sum = sum + element;
}
```

- Read the loop as "for each `element` in `values`"
- Traditional alternative:

```
double[] values = ...;
double sum = 0;
for (int i = 0; i < values.length; i++)
{
   double element = values[i];
   sum = sum + element;
}
```

The Enhanced `for` Loop

- Works for `ArrayLists` too:

```
ArrayList<BankAccount> accounts = ...;
double sum = 0;
for (BankAccount account : accounts)
{
   sum = sum + aaccount.getBalance();
}
```

- Equivalent to the following ordinary `for` loop:

```
double sum = 0;
for (int i = 0; i < accounts.size(); i++)
{
   BankAccount account = accounts.get(i);
   sum = sum + account.getBalance();
}
```

The Enhanced `for` Loop

- The “for each loop” does not allow you to modify the contents of an array:

```
for (double element : values)
{
   element = 0;
   // ERROR—this assignment does not
   // modify array element
}
```

- Must use an ordinary `for` loop:

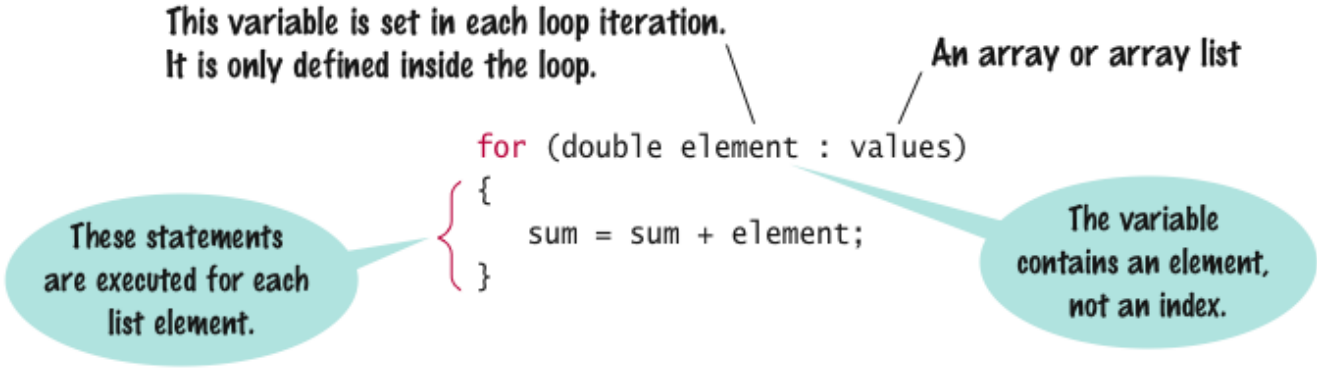
```
for (int i = 0; i < values.length; i++)
{
   values[i] = 0; // OK
}
```

Syntax 6.3 The "for each" Loop

Syntax

```
for (typeName variable : collection)
   statement
```

Example



Self Check 6.7

Write a “for each” loop that prints all elements in the array `values`.

Answer:

```
for (double element : values)
   System.out.println(element);
```

Self Check 6.8

What does this “for each” loop do?

```
int counter = 0; for (BankAccount a :
accounts)
{
   if (a.getBalance() == 0) { counter++; }
}
```

Answer: It counts how many accounts have a zero balance.

Partially Filled Arrays

- Array length = maximum number of elements in array
- Usually, array is partially filled
- Need companion variable to keep track of current size
  - *Uniform naming convention:*

```
final int VALUES_LENGTH = 100;
double[] values = new double[VALUES_LENGTH];
int valuesSize = 0;
```

- Update `valuesSize` as array is filled:

```
values[valuesSize] = x;
valuesSize++;
```

Partially Filled Arrays

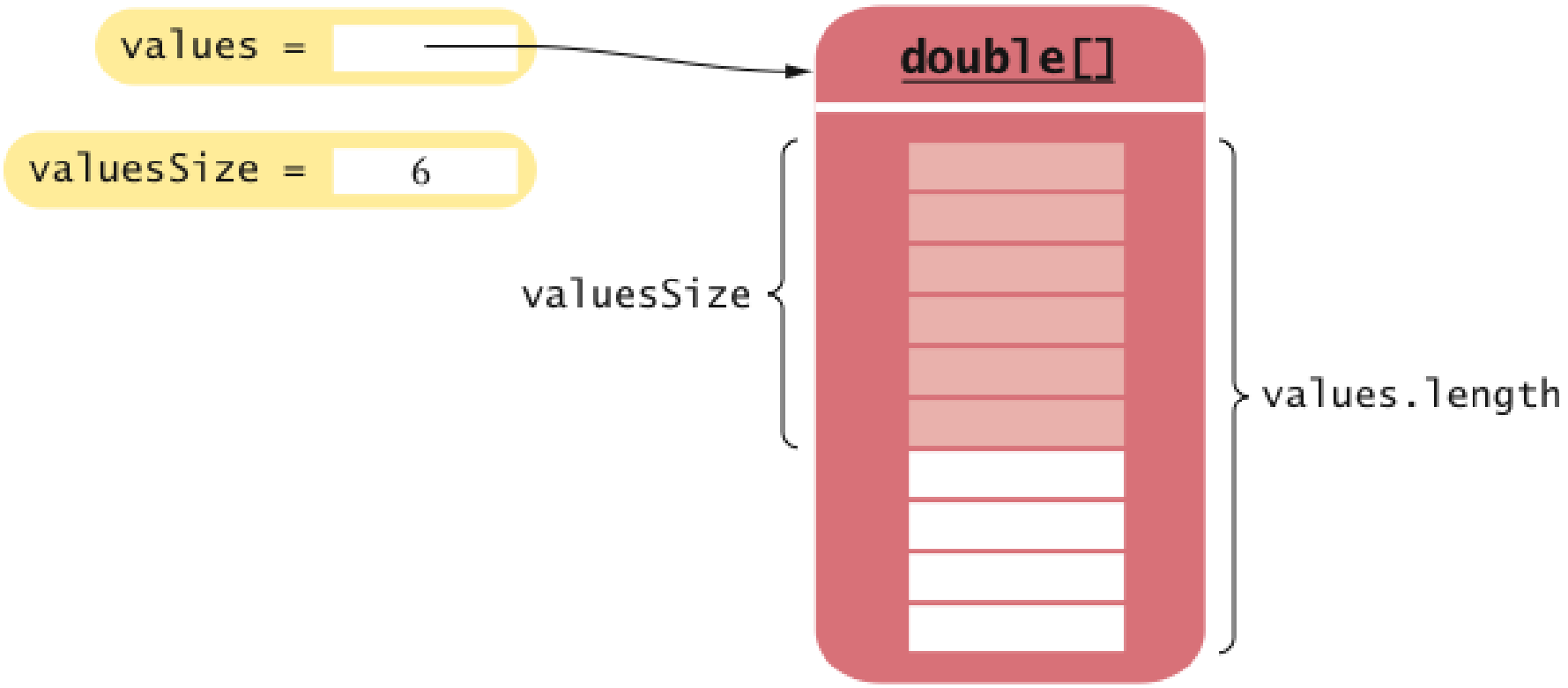


Figure 8 A Partially Filled Array

Partially Filled Arrays

- Example: Read numbers into a partially filled array:

```
int valuesSize = 0;
Scanner in = new Scanner(System.in);
while (in.hasNextDouble())
{
   if (valuesSize < values.length)
   {
      values[valuesSize] = in.nextDouble();
      valuesSize++;
   }
}
```

- To process the gathered array elements, use the companion variable, not the array length:

```
for (int i = 0; i < valuesSize; i++)
{
   System.out.println(values[i]);
}
```

Self Check 6.9

Write a loop to print the elements of the partially filled array `values` in reverse order, starting with the last element.

Answer:

```
for (int i = valuesSize - 1; i >= 0; i--)
   System.out.println(values[i]);
```

Self Check 6.10

How do you remove the last element of the partially filled array `values`?

Answer:

```
valuesSize--;
```

Self Check 6.11

Why would a programmer use a partially filled array of numbers instead of an array list?

Answer: You need to use wrapper objects in an `ArrayList<Double>`, which is less efficient.

Common Array Algorithm: Filling

- Fill an array with zeroes:

```
for (int i = 0; i < values.length; i++)
{
   values[i] = 0;
}
```

- Fill an array list with squares (0, 1, 4, 9, 16, ...):

```
for (int i = 0; i < values.size(); i++)
{
   values.set(i, i * i;
}
```

Common Array Algorithm: Computing Sum and Average

- To compute the sum of all elements, keep a running total:

```
double total = 0;
for (double element : values)
{
   total = total + element;
}
```

- To obtain the average, divide by the number of elements:

```
double average = total /values.size();
// for an array list
```

- Be sure to check that the size is not zero

Common Array Algorithm: Counting Matches

- Check all elements and count the matches until you reach the end
- Example: Count the number of accounts whose balance is at least as much as a given threshold:

```
public class Bank
{
   private ArrayList<BankAccount> accounts;

   public int count(double atLeast)
   {
      int matches = 0;
      for (BankAccount account : accounts)
      {
         if (account.getBalance() >= atLeast) matches++; // Found a
match
      }
      return matches;
   }
   . . .
}
```

Common Array Algorithm: Finding the Maximum or Minimum

- Initialize a candidate with the starting element
- Compare candidate with remaining elements
- Update it if you find a larger or smaller value

Common Array Algorithm: Finding the Maximum or Minimum

- Example: Find the account with the largest balance in the bank:

```
BankAccount largestYet = accounts.get(0);
for (int i = 1; i < accounts.size(); i++)
{
   BankAccount a = accounts.get(i);
   if (a.getBalance() > largestYet.getBalance())
      largestYet = a;
}
return largestYet;
```

- Works only if there is at least one element in the array list — if list is empty, return `null`:

```
if (accounts.size() == 0) return null;
BankAccount largestYet = accounts.get(0);
...
```

Common Array Algorithm: Searching for a Value

- Check all elements until you have found a match
- Example: Determine whether there is a bank account with a particular account number in the bank:

```
public class Bank
{
   public BankAccount find(int accountNumber)
   {
      for (BankAccount account : accounts)
      {
         if (account.getAccountNumber() == accountNumber)
            // Found a match
            return account;
      }
      return null; // No match in the entire array list
   }
   ...
}
```

Common Array Algorithm: Searching for a Value

- The process of checking all elements until you have found a match is called a **linear search**

Common Array Algorithm: Locating the Position of an Element

- Problem: Locate the position of an element so that you can replace or remove it
- Use a variation of the linear search algorithm, but remember the position instead of the matching element
- Example: Locate the position of the first element that is larger than 100:

```
int pos = 0;
boolean found = false;
while (pos < values.size() && !found)
{
   if (values.get(pos) > 100) { found = true; }
   else { pos++; }
}
if (found) { System.out.println("Position: " + pos); }
else { System.out.println("Not found"); }
```

Common Array Algorithm: Removing an Element

- Array list ⇒ use method `remove`
- Unordered array ⇒
  1. *Overwrite the element to be removed with the last element of the array*
  2. *Decrement the variable tracking the size of the array*

```
values[pos] = values[valuesSize - 1];
valuesSize--;
```

Common Array Algorithm: Removing an Element

- Ordered array ⇒
  1. *Move all elements following the element to be removed to a lower index*
  2. *Decrement the variable tracking the size of the array*

```
for (int i = pos; i < valuesSize - 1; i++)
{
   values[i] = values[i + 1];
}
valuesSize--;
```

Common Array Algorithm: Removing an Element

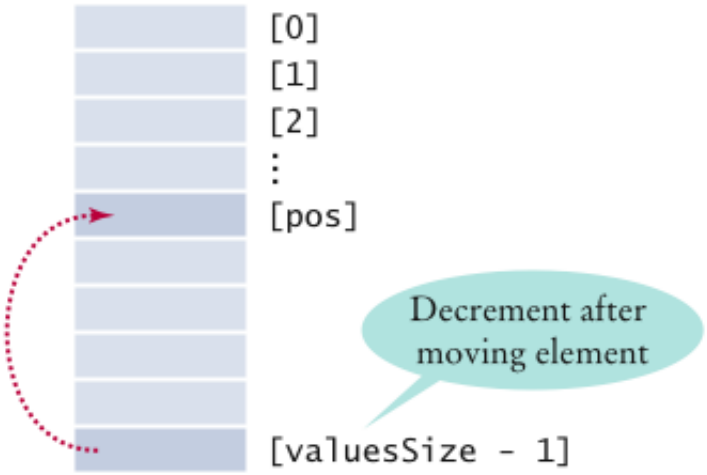


Figure 9
Removing an Element in an Unordered Array

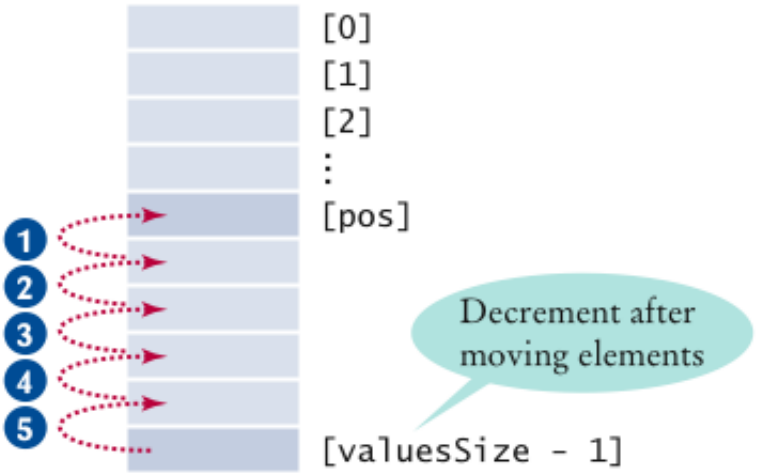


Figure 10
Removing an Element in an Ordered Array

Common Array Algorithm: Inserting an Element

- Array list ⇒ use method `add`
- Unordered array ⇒
  1. *Insert the element as the last element of the array*
  2. *Increment the variable tracking the size of the array*

```
if (valuesSize < values.length)
{
   values[valuesSize] = newElement;
   valuesSize++;
}
```

Common Array Algorithm: Inserting an Element

- Ordered array ⇒
  1. *Start at the end of the array, move that element to a higher index, then move the one before that, and so on until you finally get to the insertion location*
  2. *Insert the element*
  3. *Increment the variable tracking the size of the array*

```
if (valuesSize < values.length)
{
   for (int i = valuesSize; i > pos; i--)
   {
      values[i] = values[i - 1];
   }
   values[pos] = newElement;
   valuesSize++;
}
```

Common Array Algorithm: Inserting an Element

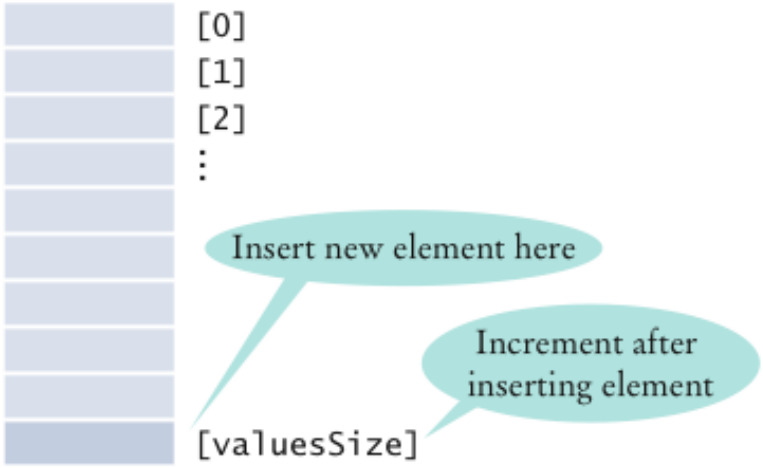


Figure 11
Inserting an Element in an Unordered Array

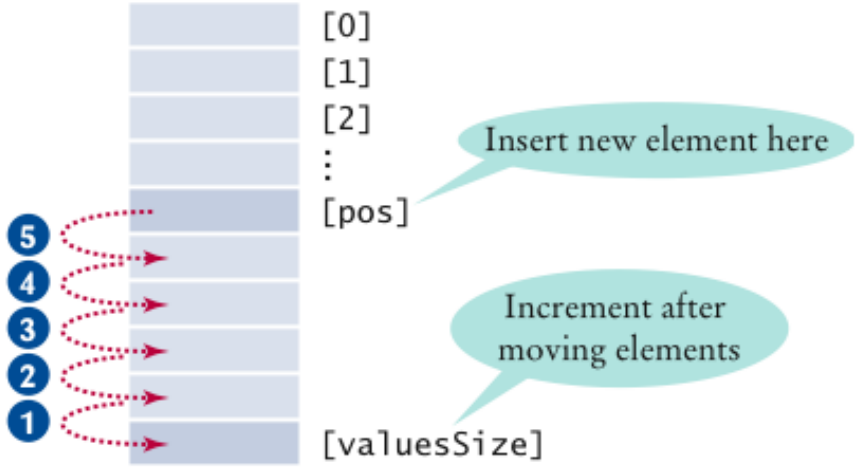
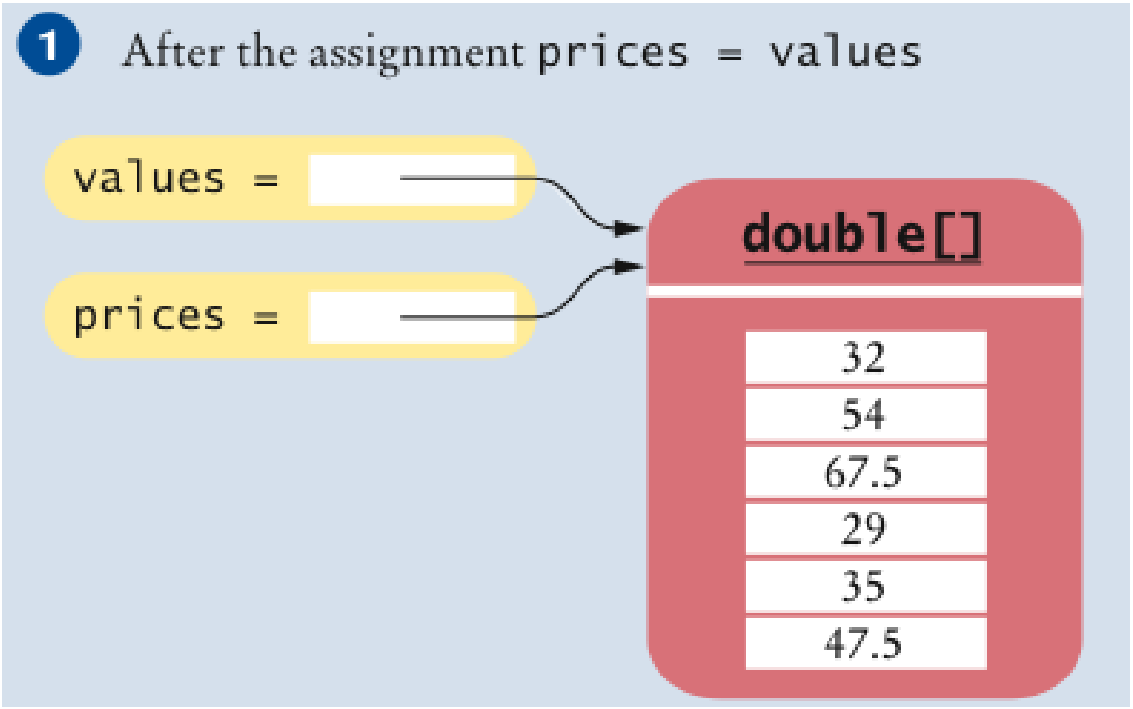


Figure 12
Inserting an Element in an Ordered Array

Common Array Algorithm: Copying an Array

- Copying an array variable yields a second reference to the same array:

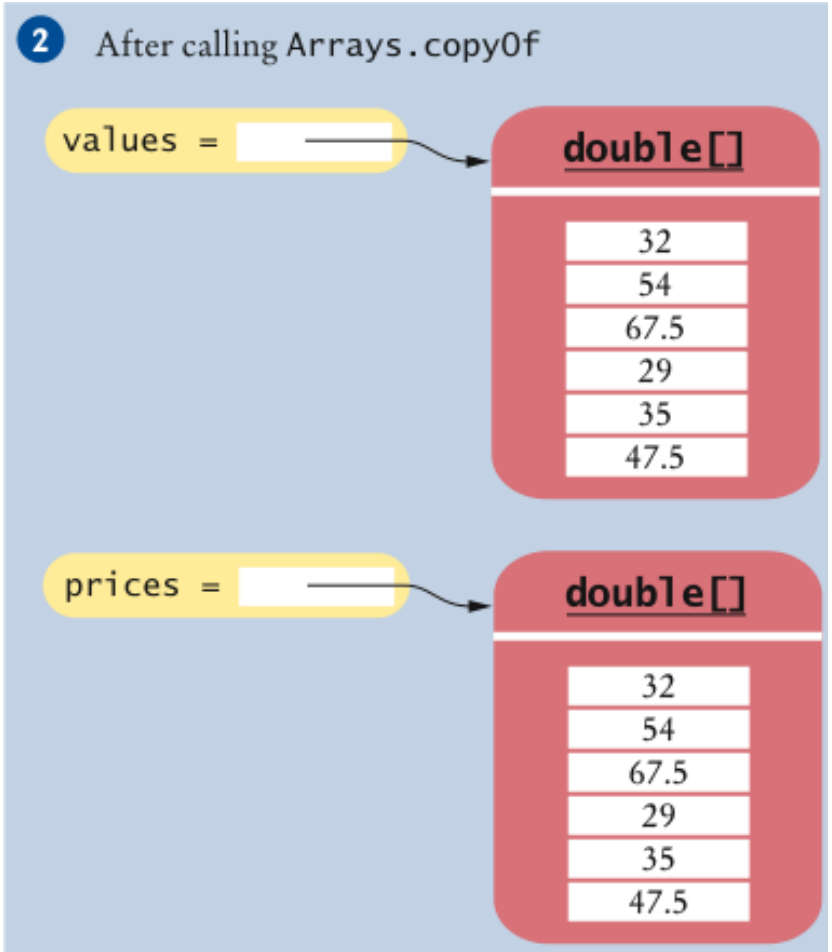
```
double[] values = new double[6];
. . .  // Fill array
double[] prices = values;
```



Common Array Algorithm: Copying an Array

- To make a true copy of an array, call the `Arrays.copyOf` method:

```
double[] prices = Arrays.copyOf(values, values.length);
```
2



Common Array Algorithm: Copying an Array

- To grow an array that has run out of space, use the `Arrays.copyOf` method:

```
values = Arrays.copyOf(values, 2 * values.length);
```

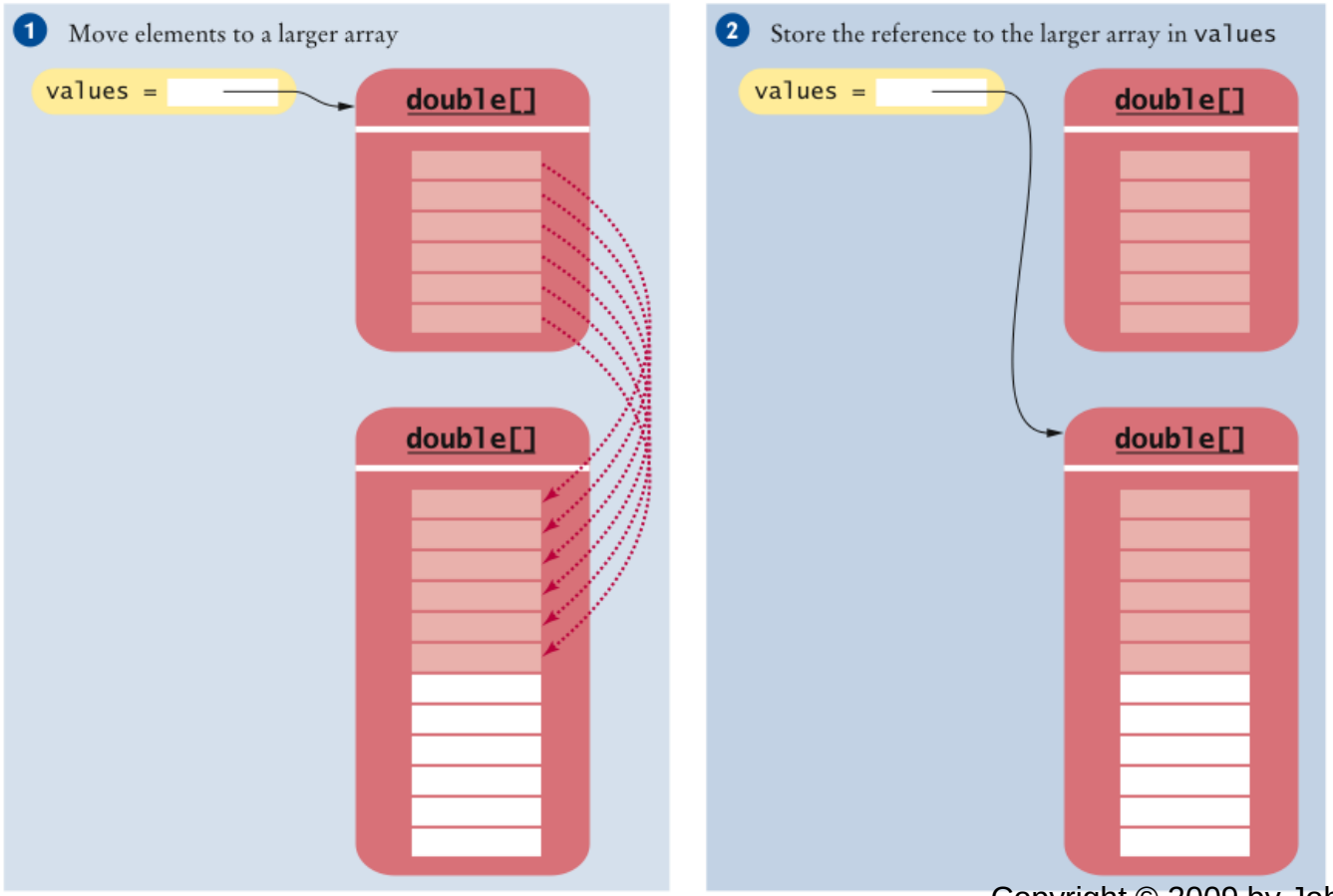


Figure 14 Growing an Array

Common Array Algorithm: Growing an Array

- Example: Read an arbitrarily long sequence numbers into an array, without running out of space:

```
int valuesSize = 0;
while (in.hasNextDouble())
{
   if (valuesSize == values.length)
      values = Arrays.copyOf(values, 2 * values.length);
   values[valuesSize] = in.nextDouble();
   valuesSize++;
}
```

Common Array Algorithm: Printing Element Separators

- When you display the elements of an array or array list, you usually want to separate them:

```
Ann | Bob | Cindy
```

- When you display the elements of an array or array list, you usually want to separate them
- Print the separator before each element *except the initial one* (with index 0):

```
for (int i = 0; i < names.size(); i++)
{
   if (i > 0)
   {
      System.out.print(" | ");
   }
   System.out.print(names.get(i));
}
```

ch06/bank/Bank.java

- `Bank` class stores an array list of bank accounts
- Methods of the `Bank` class use some of the previous algorithms:

```
1  import java.util.ArrayList;
2
3  /**
4     This bank contains a collection of bank accounts.
5  */
6  public class Bank
7  {
8     private ArrayList<BankAccount> accounts;
9
10    /**
11       Constructs a bank with no bank accounts.
12    */
13    public Bank()
14    {
15       accounts = new ArrayList<BankAccount>();
16    }
17
```

Continued

ch06/bank/Bank.java (cont.)

```
18      /**
19         Adds an account to this bank.
20         @param a the account to add
21      */
22      public void addAccount(BankAccount a)
23      {
24         accounts.add(a);
25      }
26
27      /**
28         Gets the sum of the balances of all accounts in this bank.
29         @return the sum of the balances
30      */
31      public double getTotalBalance()
32      {
33         double total = 0;
34         for (BankAccount a : accounts)
35         {
36            total = total + a.getBalance();
37         }
38         return total;
39      }
40
```

Continued

ch06/bank/Bank.java (cont.)

```
41      /**
42         Counts the number of bank accounts whose balance is at
43         least a given value.
44         @param atLeast the balance required to count an account
45         @return the number of accounts having least the given balance
46      */
47      public int countBalancesAtLeast(double atLeast)
48      {
49         int matches = 0;
50         for (BankAccount a : accounts)
51         {
52            if (a.getBalance() >= atLeast) matches++; // Found a match
53         }
54         return matches;
55      }
56
```

Continued

ch06/bank/Bank.java (cont.)

```
57      /**
58         Finds a bank account with a given number.
59         @param accountNumber the number to find
60         @return the account with the given number, or null if there
61         is no such account
62      */
63      public BankAccount find(int accountNumber)
64      {
65         for (BankAccount a : accounts)
66         {
67            if (a.getAccountNumber() == accountNumber) // Found a match
68               return a;
69         }
70         return null; // No match in the entire array list
71      }
72
```

Continued

ch06/bank/Bank.java (cont.)

```
73      /**
74         Gets the bank account with the largest balance.
75         @return the account with the largest balance, or null if the
76         bank has no accounts
77      */
78      public BankAccount getMaximum()
79      {
80         if (accounts.size() == 0) return null;
81         BankAccount largestYet = accounts.get(0);
82         for (int i = 1; i < accounts.size(); i++)
83         {
84            BankAccount a = accounts.get(i);
85            if (a.getBalance() > largestYet.getBalance())
86               largestYet = a;
87         }
88         return largestYet;
89      }
90   }
```

ch06/bank/BankTester.java

```
1  /**
2     This program tests the Bank class.
3  */
4  public class BankTester
5  {
6     public static void main(String[] args)
7     {
8        Bank firstBankOfJava = new Bank();
9        firstBankOfJava.addAccount(new BankAccount(1001, 20000));
10       firstBankOfJava.addAccount(new BankAccount(1015, 10000));
11       firstBankOfJava.addAccount(new BankAccount(1729, 15000));
12
13       double threshold = 15000;
14       int count = firstBankOfJava.countBalancesAtLeast(threshold);
15       System.out.println("Count: " + count);
16       System.out.println("Expected: 2");
17
```

Continued

ch06/bank/BankTester.java (cont.)

```
18          int accountNumber = 1015;
19          BankAccount account = firstBankOfJava.find(accountNumber);
20          if (account == null)
21             System.out.println("No matching account");
22          else
23             System.out.println("Balance of matching account: "
24                + account.getBalance());
25          System.out.println("Expected: 10000");
26
27          BankAccount max = firstBankOfJava.getMaximum();
28          System.out.println("Account with largest balance: "
29                + max.getAccountNumber());
30          System.out.println("Expected: 1001");
31       }
32    }
```

Program Run:

```
Count: 2
Expected: 2
Balance of matching account: 10000.0
Expected: 10000
Account with largest balance: 1001
Expected: 1001
```

Self Check 6.12

What does the `find` method do if there are two bank accounts with a matching account number?

Answer: It returns the first match that it finds.

Self Check 6.13

Would it be possible to use a “for each” loop in the `getMaximum` method?

Answer: Yes, but the first comparison would always fail.

Self Check 6.14

When printing separators, we skipped the separator before the initial element. Rewrite the loop so that the separator is printed *after* each element, except for the last element.

Answer:

```
for (int i = 0; i < values.size(); i++)
{
   System.out.print(values.get(i));
   if (i < values.size() - 1)
   {
      System.out.print(" | ");
   }
}
```

Now you know why we set up the loop the other way.

Self Check 6.15

The following replacement has been suggested for the algorithm that prints element separators:

```
System.out.print(names.get(0));
for (int i = 1; i < names.size(); i++)
   System.out.print(" | " + names.get(i));
```

What is problematic about this suggestion?

Answer: If `names` happens to be empty, the first line causes a bounds error.

Regression Testing

- **Test suite:** a set of tests for repeated testing
- **Cycling:** bug that is fixed but reappears in later versions
- **Regression testing:** repeating previous tests to ensure that known failures of prior versions do not appear in new versions

ch06/regression/BankTester.java

```
1  import java.util.Scanner;
2
3  /**
4     This program tests the Bank class.
5  */
6  public class BankTester
7  {
8     public static void main(String[] args)
9     {
10       Bank firstBankOfJava = new Bank();
11       firstBankOfJava.addAccount(new BankAccount(1001, 20000));
12       firstBankOfJava.addAccount(new BankAccount(1015, 10000));
13       firstBankOfJava.addAccount(new BankAccount(1729, 15000));
14
15       Scanner in = new Scanner(System.in);
16
17       double threshold = in.nextDouble();
18       int c = firstBankOfJava.count(threshold);
19       System.out.println("Count: " + c);
20       int expectedCount = in.nextInt();
21       System.out.println("Expected: " + expectedCount);
22
```

Continued

ch06/regression/BankTester.java (cont.)

```
23          int accountNumber = in.nextInt();
24          BankAccount a = firstBankOfJava.find(accountNumber);
25          if (a == null)
26             System.out.println("No matching account");
27          else
28          {
29             System.out.println("Balance of matching account: " + a.getBalance());
30             int matchingBalance = in.nextInt();
31             System.out.println("Expected: " + matchingBalance);
32          }
33       }
34    }
```

Regression Testing: Input Redirection

- Store the inputs in a file
- ch06/regression/input1.txt:

```
15000
2
1015
10000
```

- Type the following command into a shell window:

```
java BankTester < input1.txt
```

- Program Run:

```
Count: 2
Expected: 2
Balance of matching account: 10000
Expected: 10000
```

Regression Testing: Output Redirection

- Output redirection:

```
java BankTester < input1.txt > output1.txt
```

Self Check 6.16

Suppose you modified the code for a method. Why do you want to repeat tests that already passed with the previous version of the code?

Answer: It is possible to introduce errors when modifying code.

Self Check 6.17

Suppose a customer of your program finds an error. What action should you take beyond fixing the error?

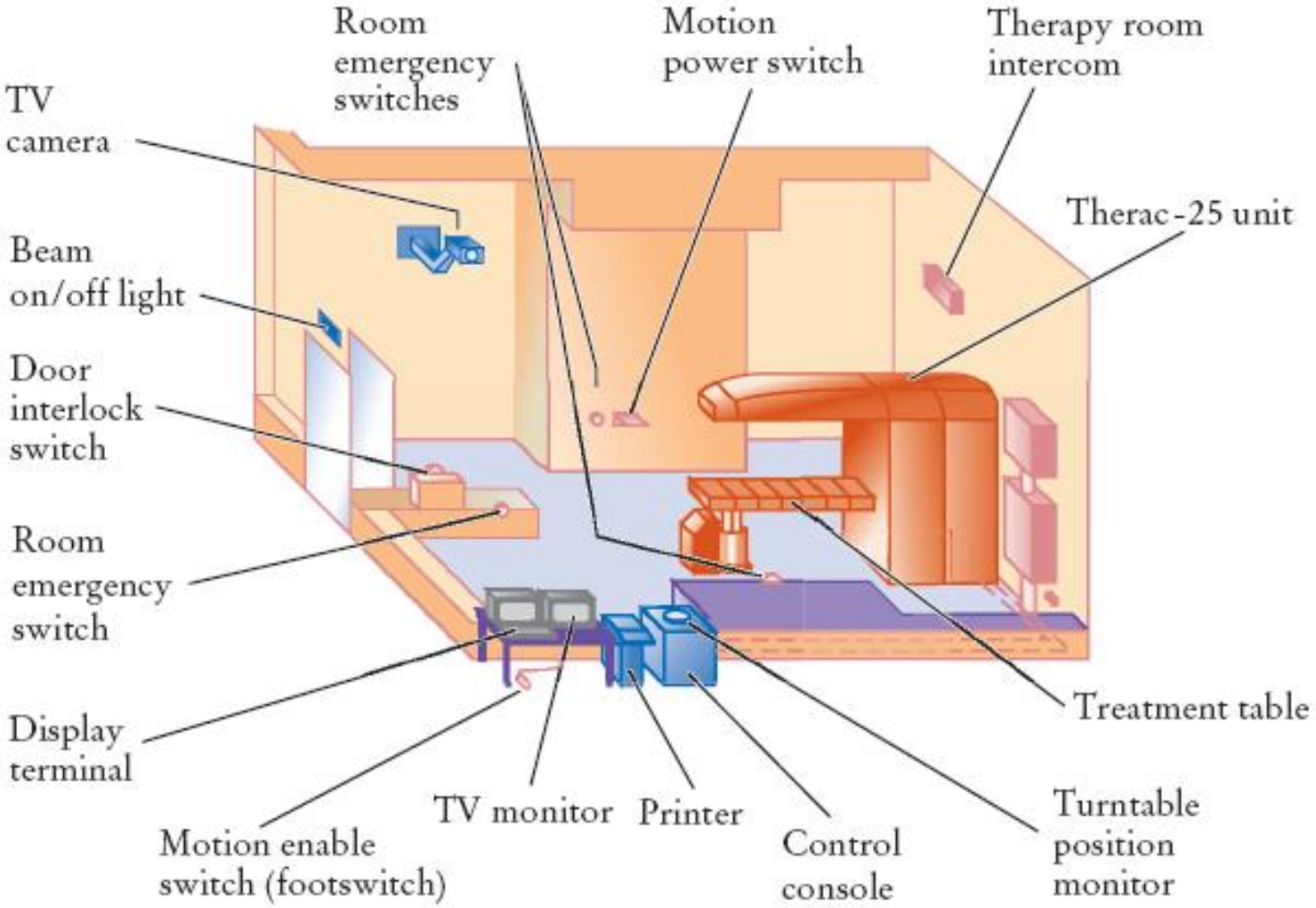
Answer: Add a test case to the test suite that verifies that the error is fixed.

Self Check 6.18

Why doesn't the `BankTester` program contain prompts for the inputs?

Answer: There is no human user who would see the prompts because input is provided from a file.

Therac-25 Facility



Typical Therac-25 Facility

Two-Dimensional Arrays

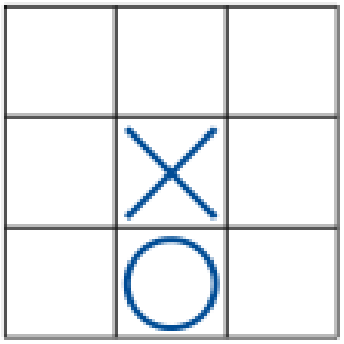


Figure 15 A Tic-Tac-Toe Board

- When constructing a two-dimensional array, specify how many rows and columns are needed:

```
final int ROWS = 3;
final int COLUMNS = 3;
String[][] board = new String[ROWS][COLUMNS];
```

- Access elements with an index pair:

```
board[1][1] = "x";
board[2][1] = "o";
```

Traversing Two-Dimensional Arrays

- It is common to use two nested loops when filling or searching:

```
for (int i = 0; i < ROWS; i++)
   for (int j = 0; j < COLUMNS; j++)
      board[i][j] = " ";
```

Traversing Two-Dimensional Arrays

- You can also recover the array dimensions from the array variable:
  - *board.length is the number of rows*
  - *board[0].length is the number of columns*
- Rewrite the loop for filling the tic-tac-toe board:

```
for (int i = 0; i < board.length; i++)
   for (int j = 0; j < board[0].length; j++)
      board[i][j] = " ";
```

ch06/twodim/TicTacToe.java

```
1  /**
2     A 3 x 3 tic-tac-toe board.
3  */
4  public class TicTacToe
5  {
6     private String[][] board;
7     private static final int ROWS = 3;
8     private static final int COLUMNS = 3;
9
10    /**
11       Constructs an empty board.
12    */
13    public TicTacToe()
14    {
15       board = new String[ROWS][COLUMNS];
16       // Fill with spaces
17       for (int i = 0; i < ROWS; i++)
18          for (int j = 0; j < COLUMNS; j++)
19             board[i][j] = " ";
20    }
21
```

Continued

ch06/twodim/TicTacToe.java (cont.)

```
22      /**
23         Sets a field in the board. The field must be unoccupied.
24         @param i the row index
25         @param j the column index
26         @param player the player ("x" or "o")
27      */
28      public void set(int i, int j, String player)
29      {
30         if (board[i][j].equals(" "))
31            board[i][j] = player;
32      }
33
```

Continued

ch06/twodim/TicTacToe.java (cont.)

```
35          Creates a string representation of the board, such as
36          |x  o|
37          | x |
38          |  o|
39          @return the string representation
40       */
41       public String toString()
42       {
43          String r = "";
44          for (int i = 0; i < ROWS; i++)
45          {
46             r = r + "|";
47             for (int j = 0; j < COLUMNS; j++)
48                r = r + board[i][j];
49             r = r + "|\n";
50          }
51          return r;
52       }
53    }
```

ch06/twodim/TicTacToeRunner.java

```
 1  import java.util.Scanner;
 2
 3  /**
 4     This program runs a TicTacToe game. It prompts the
 5     user to set positions on the board and prints out the
 6     result.
 7  */
 8  public class TicTacToeRunner
 9  {
10     public static void main(String[] args)
11     {
12        Scanner in = new Scanner(System.in);
13        String player = "x";
14        TicTacToe game = new TicTacToe();
```

Continued

ch06/twodim/TicTacToeRunner.java (cont.)

```
15          boolean done = false;
16          while (!done)
17          {
18             System.out.print(game.toString());
19             System.out.print(
20                   "Row for " + player + " (-1 to exit): ");
21             int row = in.nextInt();
22             if (row < 0) done = true;
23             else
24             {
25                System.out.print("Column for " + player + ": ");
26                int column = in.nextInt();
27                game.set(row, column, player);
28                if (player.equals("x"))
29                   player = "o";
30                else
31                   player = "x";
32             }
33          }
34       }
35    }
```

ch06/twodim/TicTacToeRunner.java (cont.)

Program Run:

```
|   |
|   |
|   |
Row for x (-1 to exit): 1
Column for x: 2
|   |
|  x|
|   |
Row for o (-1 to exit): 0
Column for o: 0
|o  |
|  x|
|   |
Row for x (-1 to exit): -1
```

Self Check 6.19

How do you declare and initialize a 4-by-4 array of integers?

Answer:

```
int[][] array = new int[4][4];
```

Self Check 6.20

How do you count the number of spaces in the tic-tac-toe board?

Answer:

```
int count = 0;
for (int i = 0; i < ROWS; i++)
   for (int j = 0; j < COLUMNS; j++)
      if (board[i][j] == ' ') count++;
```