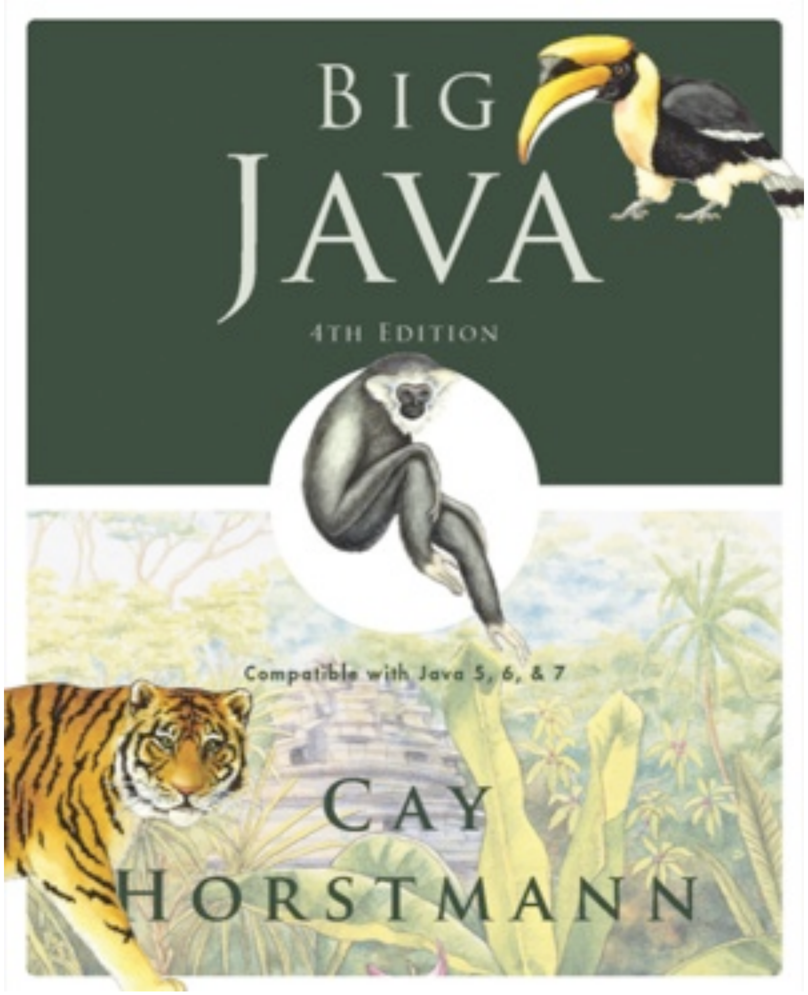
ICOM 4015: Advanced Programming

Lecture 7

Reading: Chapter Seven: Arrays and ArrayLists

Big Java by Cay Horstmann



Chapter 7 – Arrays and Array Lists

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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

T To understand the concept of regression testing

Arrays: Key Concepts

- Array is one object that can enclose a set of up to N “internal” objects
- Arrays have fixed size but may not be full
- Arrays are homogeneous, all internal objects must be of the same type
- Accessing an object in an array can be done extremely efficiently

Arrays

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

```
new double[10]
```

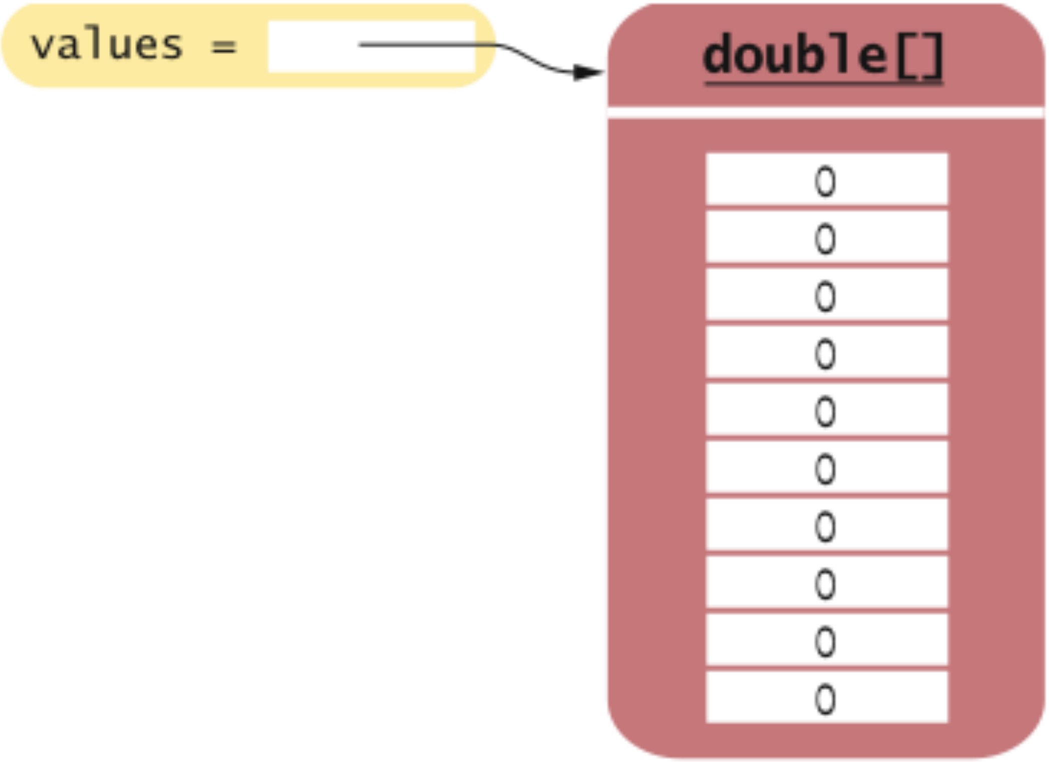
- Store in variable of type `double[]`:

```
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



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Arrays

Use `[]` to access an element:

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

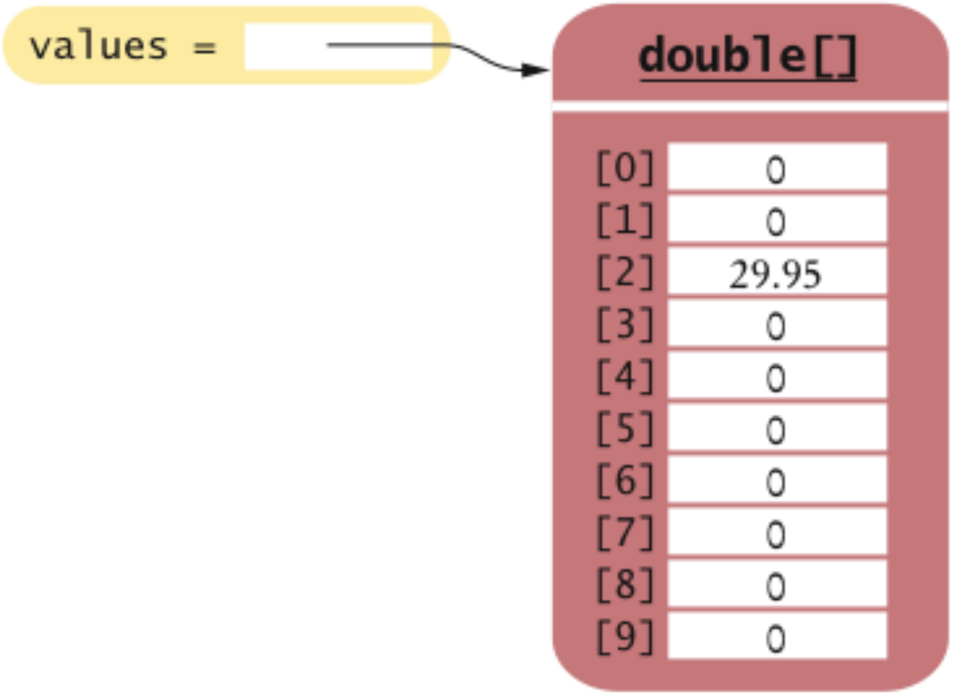

Figure 2
Modifying an Array Element

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

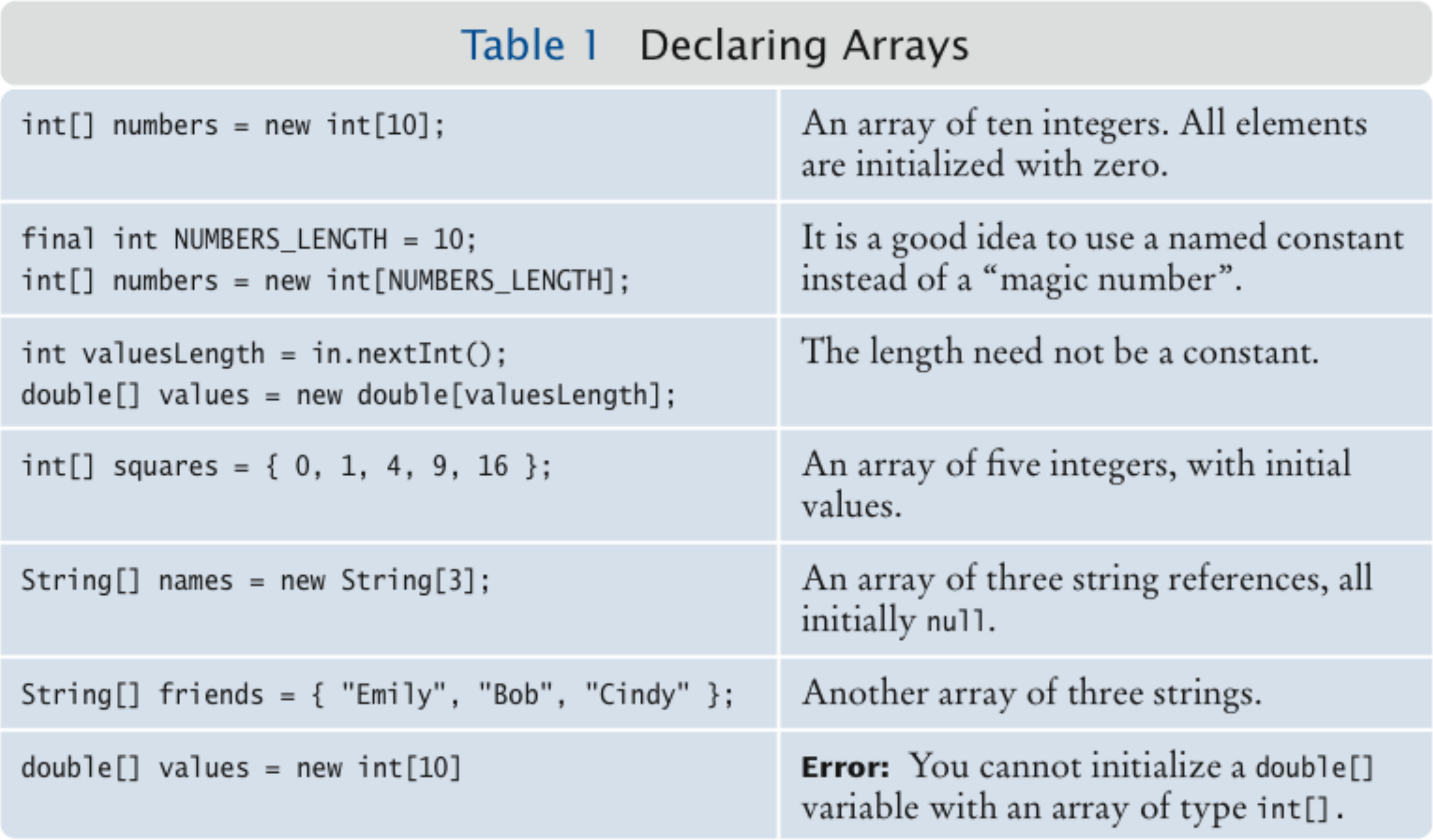

Table 1 Declaring Arrays

`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[]`.

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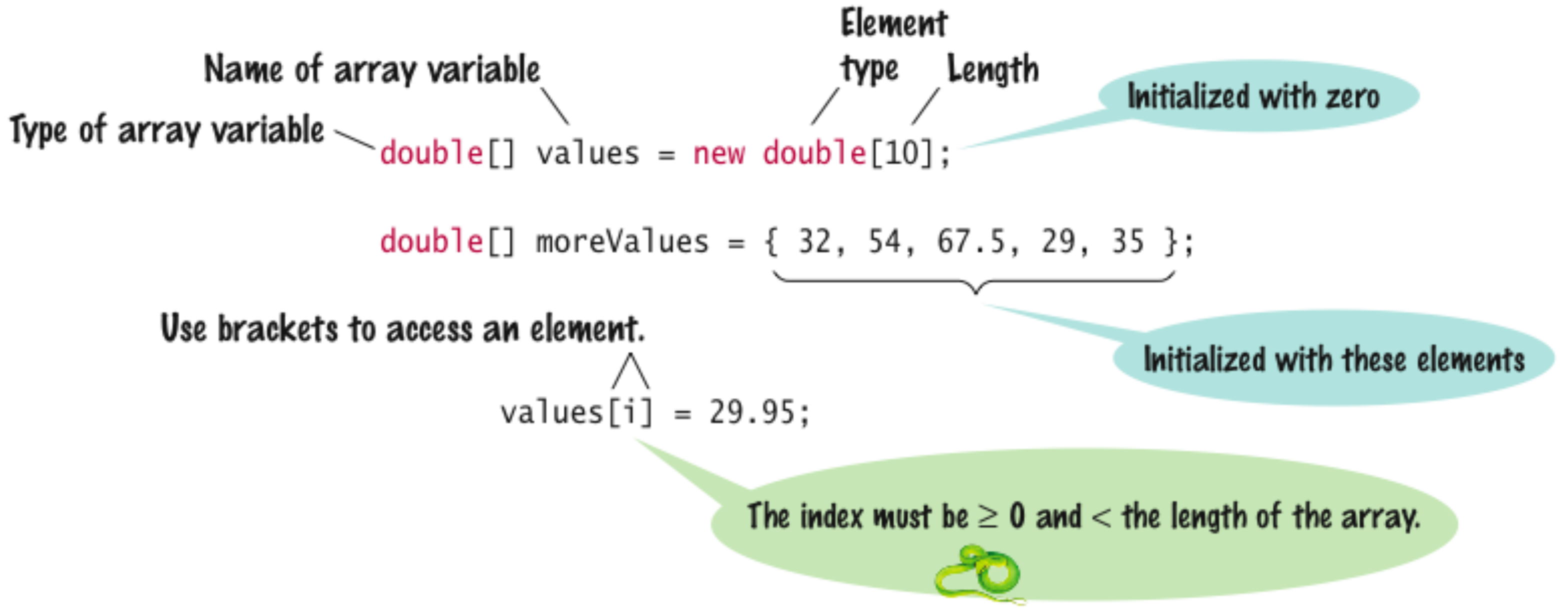
Syntax 7.1 Arrays

Syntax

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

To access an element: *arrayReference*[*index*]

Example



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

double[] moreValues = { 32, 54, 67.5, 29, 35 };

values[i] = 29.95;
```

Name of array variable

Type of array variable

Element type

Length

Initialized with zero

Initialized with these elements

Use brackets to access an element.

The index must be ≥ 0 and < the length of the array.

Self Check 7.1

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 7.2

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;
```

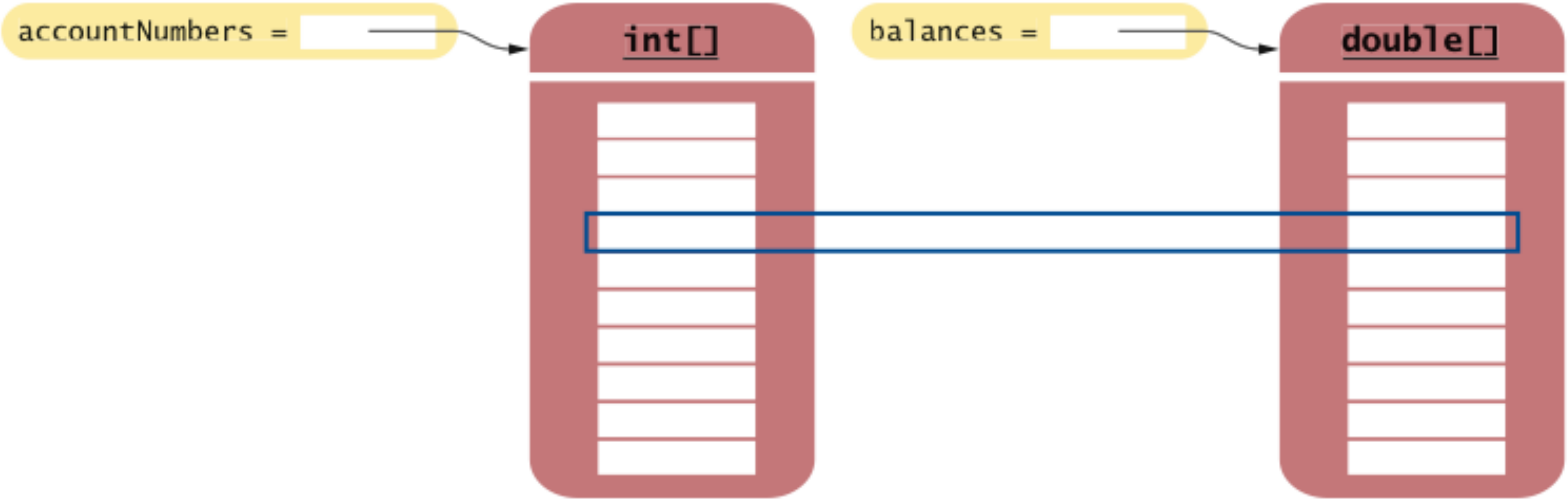


Figure 3 Avoid Parallel Arrays

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Make Parallel Arrays into Arrays of Objects

Avoid parallel arrays by changing them into arrays of objects:

```
BankAccount[] accounts;
```

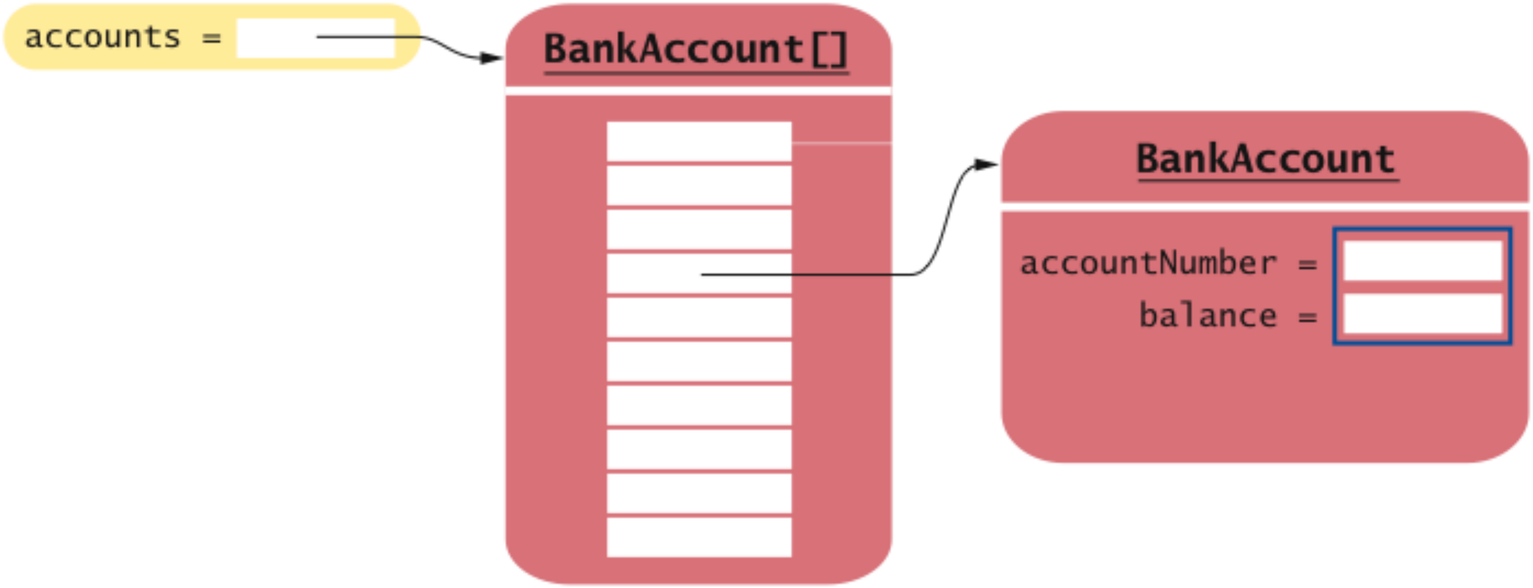

Figure 4 Reorganizing Parallel Arrays into an Array of Objects

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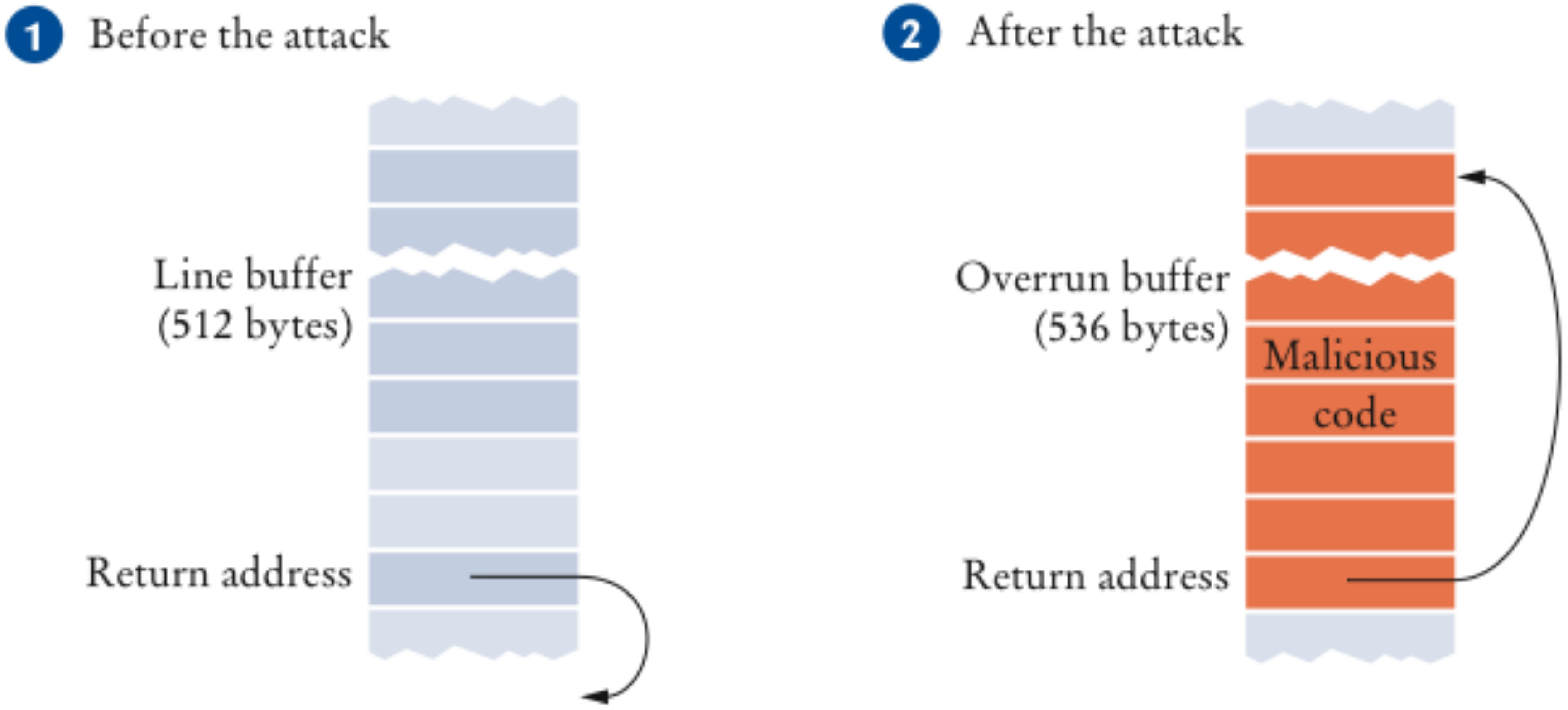
An Early Internet Worm



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

Array List: Key Concepts

- Array is one object that can enclose a set of arbitrarily many objects
- Array Lists have dynamic size
- Arrays are homogeneous, all internal objects must be of the same type
- Accessing an object in an array list could be slower than in an array

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
```

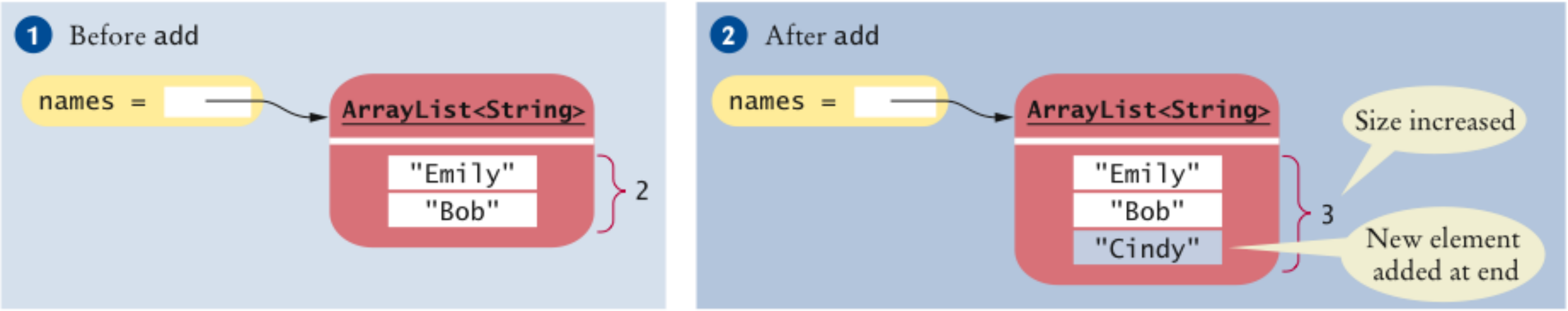


Figure 5 Adding an Element with add

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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");
```

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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");❶
names.add(1, "Ann");❷
names.remove(1);❸
```

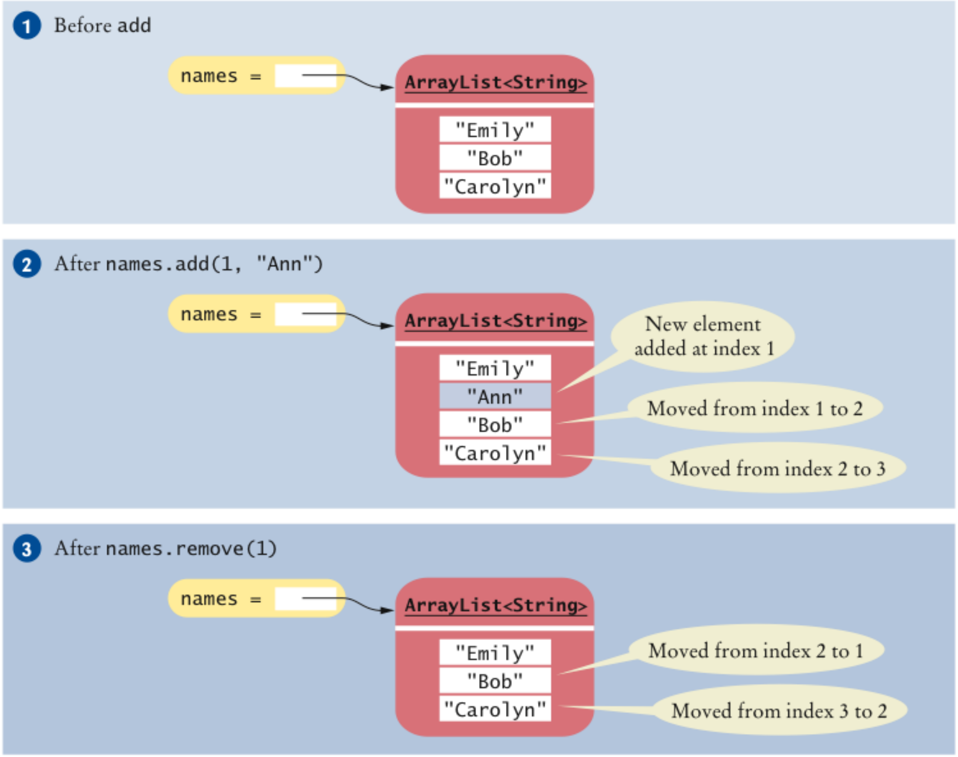


Figure 6 Adding and Removing Elements in the Middle of an Array List

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]`.

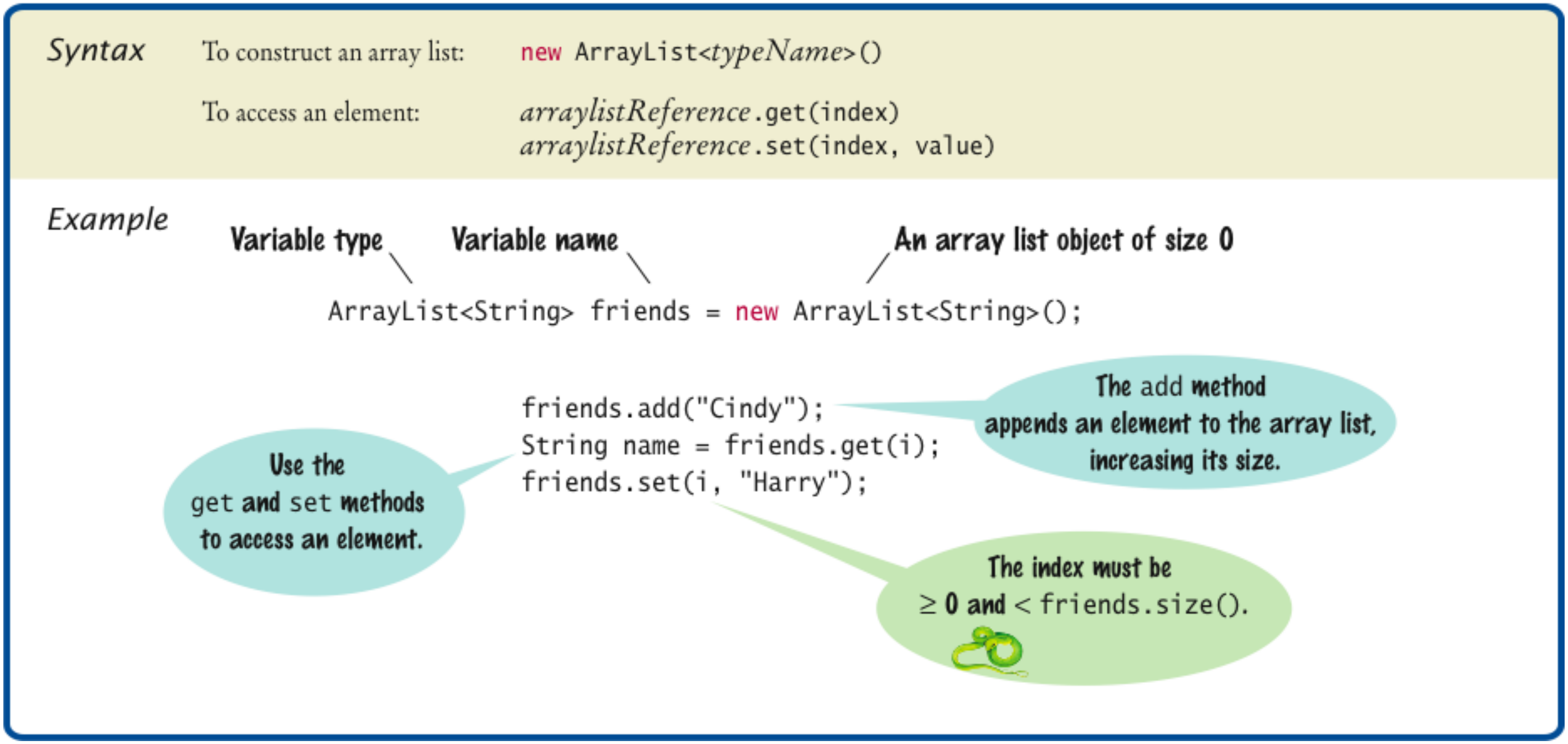
Working with Array Lists (cont.)

`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 7.2 Array Lists



Syntax

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

To access an element:

arraylistReference`.get(index)`
arraylistReference`.set(index, value)`

Example

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

Variable type

Variable name

An array list object of size 0

```
friends.add("Cindy");
String name = friends.get(i);
friends.set(i, "Harry");
```

The `add` method appends an element to the array list, increasing its size.

Use the `get` and `set` methods to access an element.

The index must be ≥ 0 and < `friends.size()`.

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
}
```

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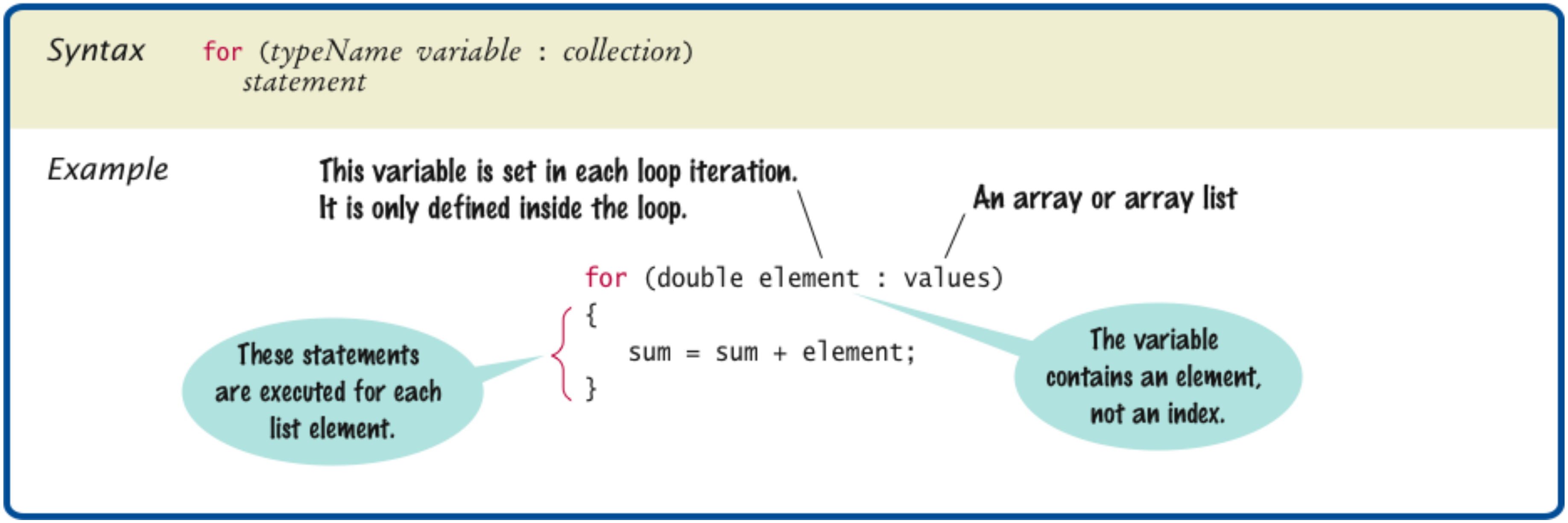
Syntax 7.3 The “for each” Loop



Syntax

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

Example

This variable is set in each loop iteration.
It is only defined inside the loop.

An array or array list

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

These statements are executed for each list element.

The variable contains an element, not an index.

Self Check 7.7

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

Answer:

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

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Self Check 7.8

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.

ch07/arraylist/ArrayListTester.java

```java
import java.util.ArrayList;

/**
   This program tests the ArrayList class.
*/
public class ArrayListTester
{
   public static void main(String[] args)
   {
      ArrayList<BankAccount> accounts = new ArrayList<BankAccount>();
      accounts.add(new BankAccount(1001));
      accounts.add(new BankAccount(1015));
      accounts.add(new BankAccount(1729));
      accounts.add(1, new BankAccount(1008));
      accounts.remove(0);

      System.out.println("Size: " + accounts.size());
      System.out.println("Expected: 3");
      BankAccount first = accounts.get(0);
      System.out.println("First account number: "
            + first.getAccountNumber());
      System.out.println("Expected: 1008");
      BankAccount last = accounts.get(accounts.size() - 1);
      System.out.println("Last account number: "
            + last.getAccountNumber());
      System.out.println("Expected: 1729");
   }
}
```

ch07/arraylist/BankAccount.java

```
/**
   A bank account has a balance that can be changed by
   deposits and withdrawals.
*/
public class BankAccount
{
   private int accountNumber;
   private double balance;

   /**
      Constructs a bank account with a zero balance.
      @param anAccountNumber the account number for this account
   */
   public BankAccount(int anAccountNumber)
   {
      accountNumber = anAccountNumber;
      balance = 0;
   }

```

Continued

ch07/arraylist/BankAccount.java (cont.)

```
   /**
      Constructs a bank account with a given balance
      @param anAccountNumber the account number for this account
      @param initialBalance the initial balance
   */
   public BankAccount(int anAccountNumber, double initialBalance)
   {
      accountNumber = anAccountNumber;
      balance = initialBalance;
   }

   /**
      Gets the account number of this bank account.
      @return the account number
   */
   public int getAccountNumber()
   {
      return accountNumber;
   }

```

Continued

ch07/arraylist/BankAccount.java (cont.)

```
    /**
        Deposits money into the bank account.
        @param amount the amount to deposit
    */
    public void deposit(double amount)
    {
        double newBalance = balance + amount;
        balance = newBalance;
    }

    /**
        Withdraws money from the bank account.
        @param amount the amount to withdraw
    */
    public void withdraw(double amount)
    {
        double newBalance = balance - amount;
        balance = newBalance;
    }

```

Continued

ch07/arraylist/BankAccount.java (cont.)

```java
   /**
      Gets the current balance of the bank account.
      @return the current balance
   */
   public double getBalance()
   {
      return balance;
   }
}
```

Program Run:

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

Self Check 7.3

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

Answer:

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

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Self Check 7.4

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

ArrayList's of Primitive Types: Use Wrapper Classes

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

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

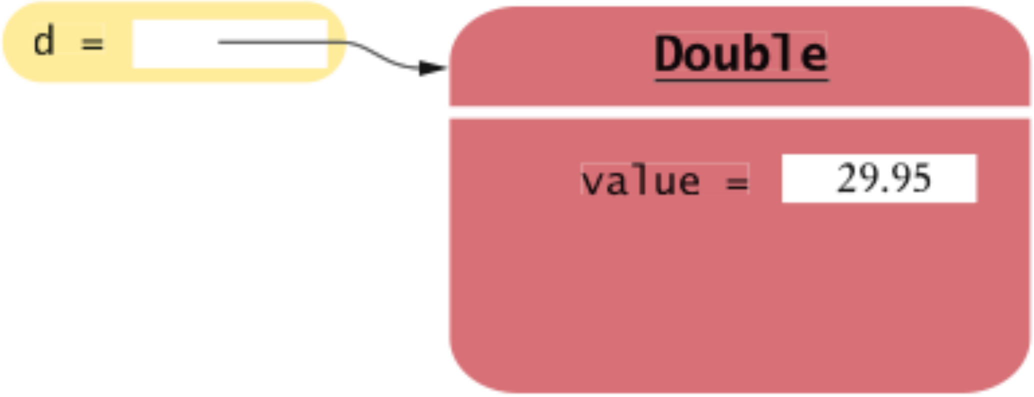

Figure 7 An Object of a Wrapper Class

- 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);
```

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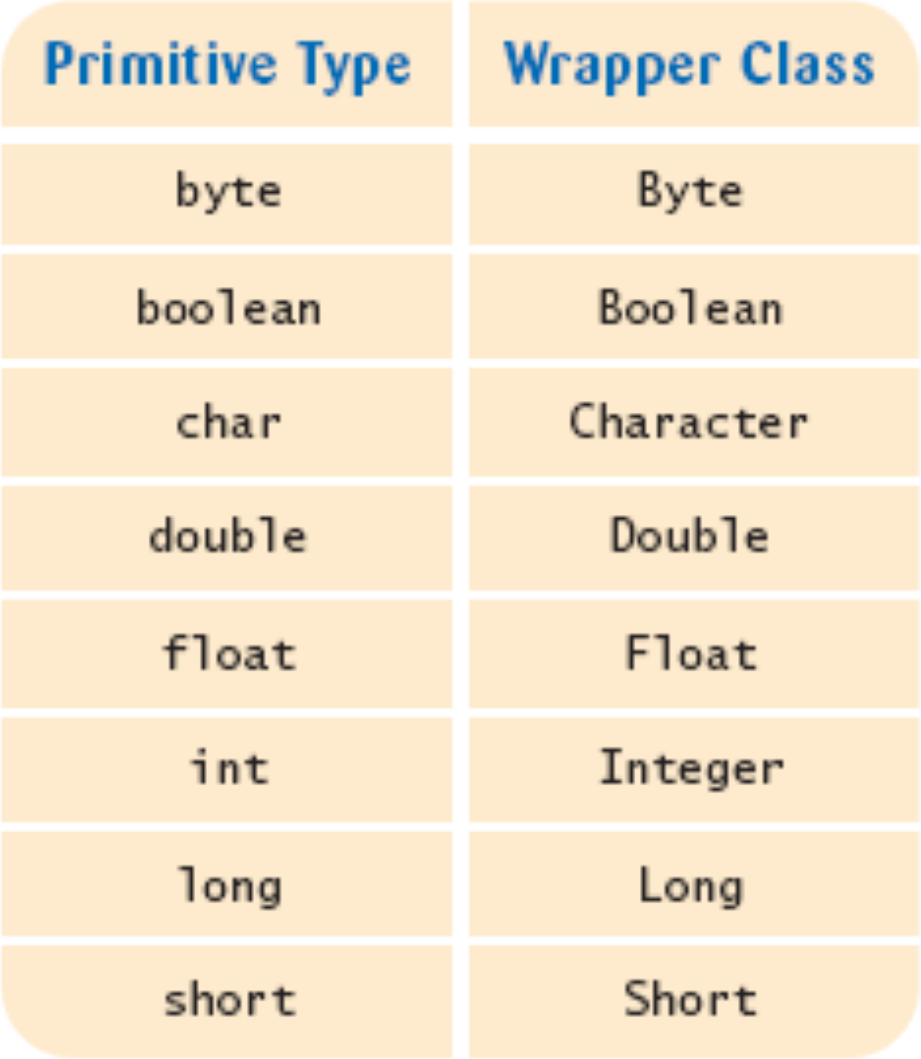
Wrappers

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`

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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 7.5

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 7.6

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);
```

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

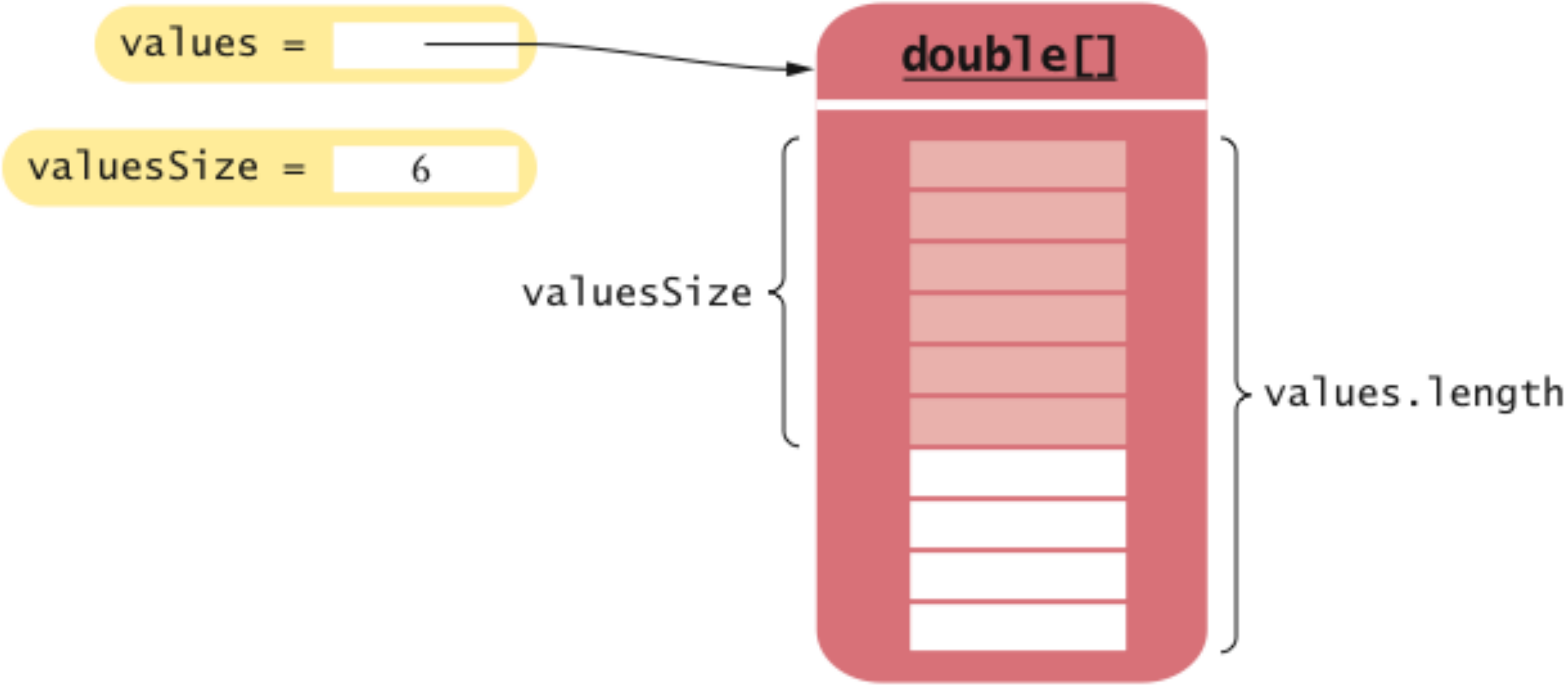

Figure 8 A Partially Filled Array

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 7.9

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 7.10

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

Answer:

```
valuesSize--;
```

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Self Check 7.11

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

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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

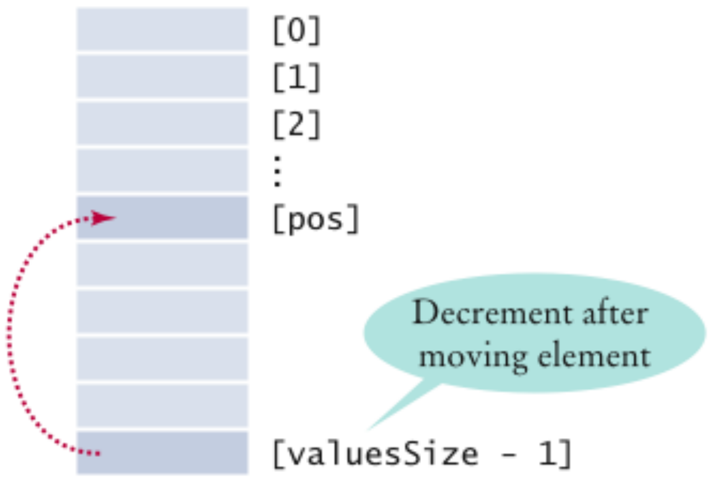


Figure 9
Removing an Element in an Unordered Array

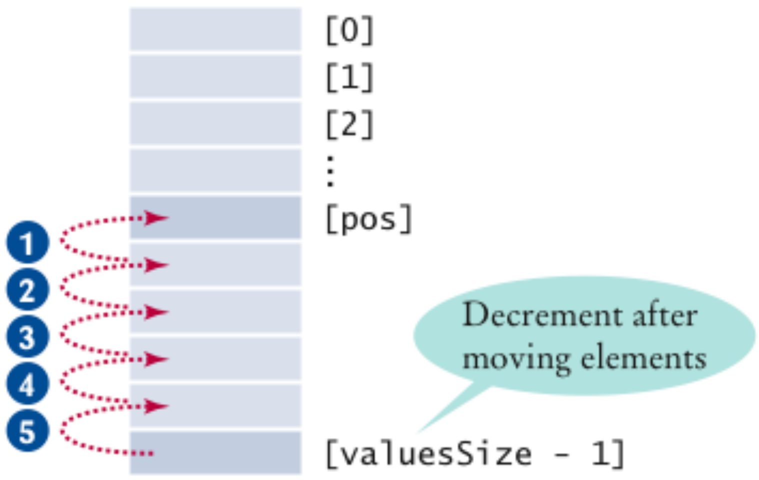
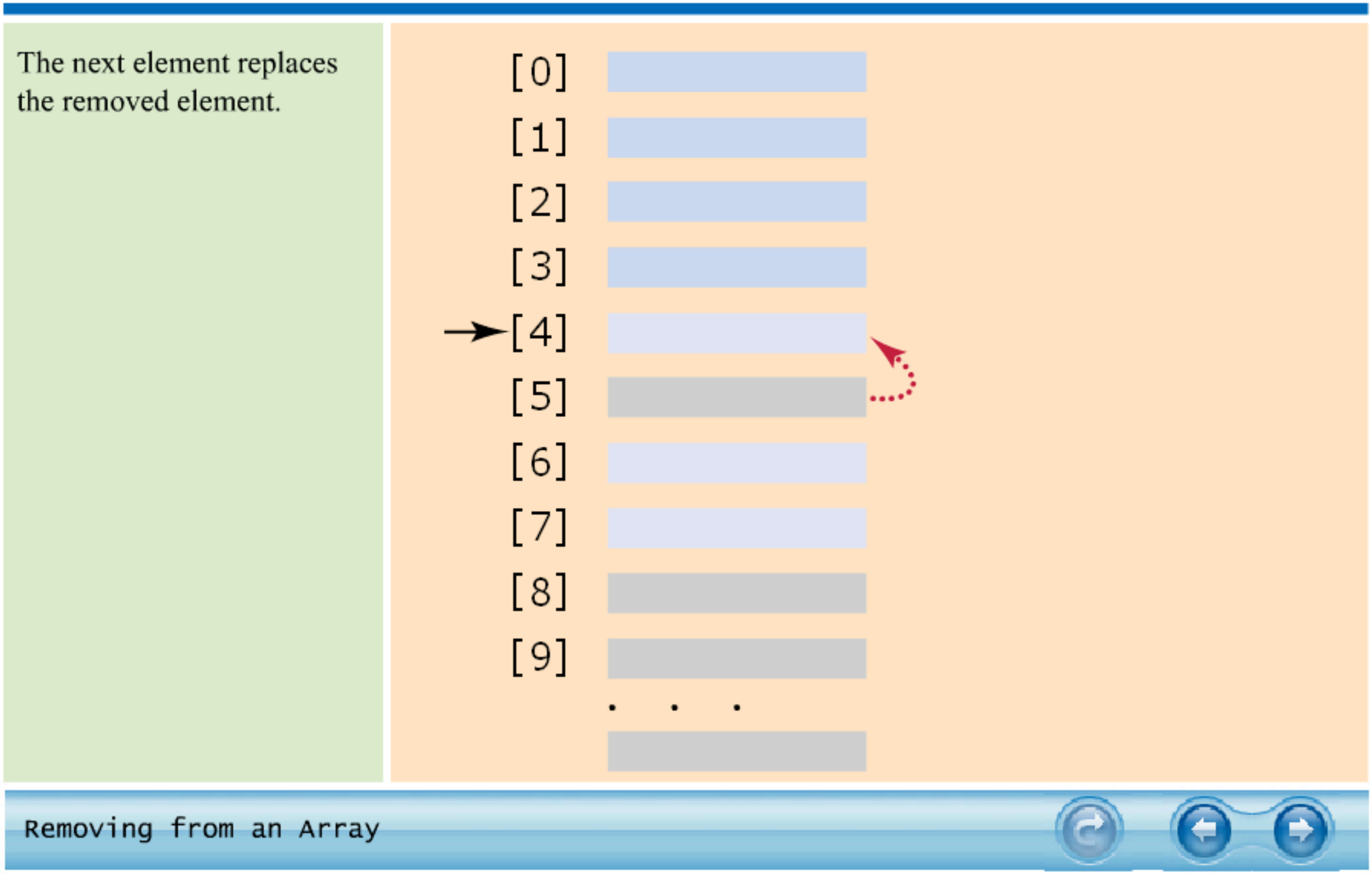


Figure 10
Removing an Element in an Ordered Array

Animation 7.1: Removing from an Array



The next element replaces the removed element.

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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

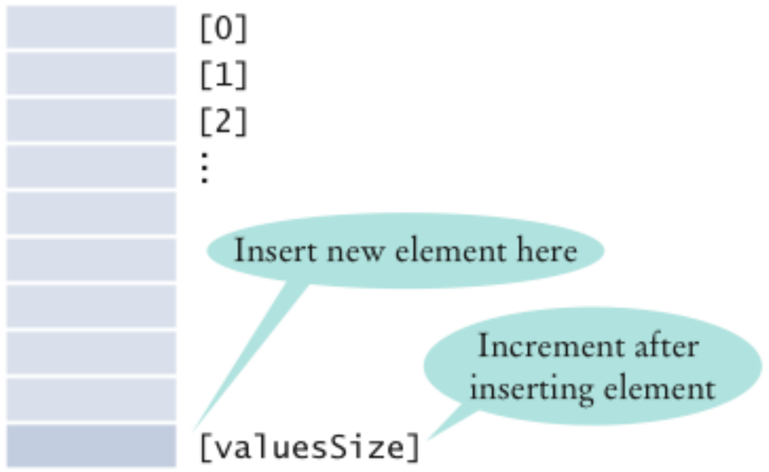


Figure 11
Inserting an Element in an Unordered Array

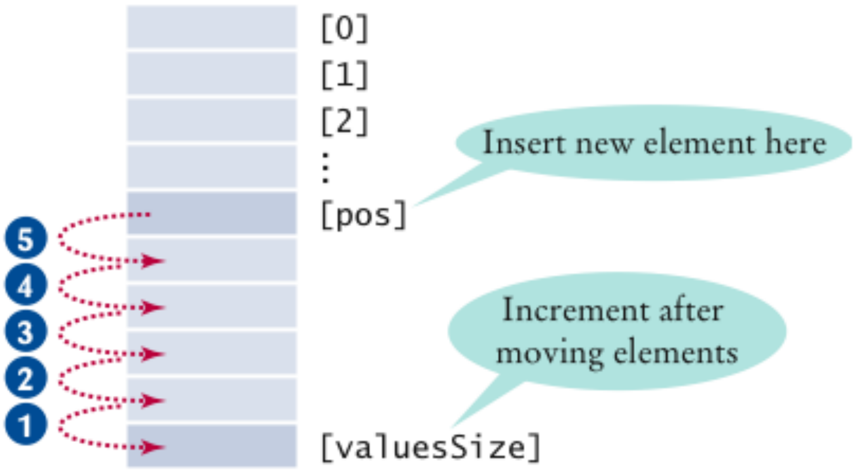
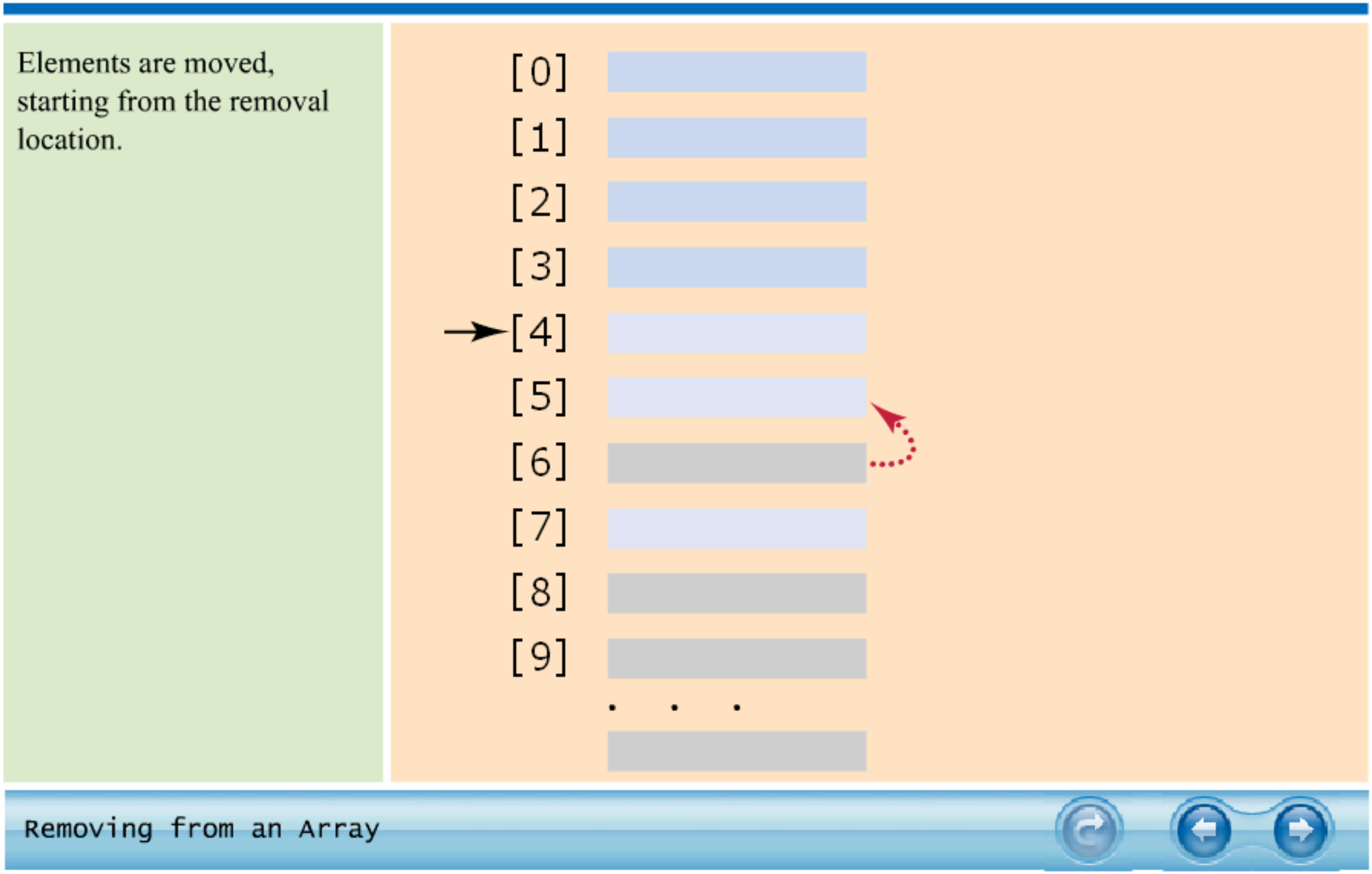


Figure 12
Inserting an Element in an Ordered Array

Animation 7.2: Inserting into an Array



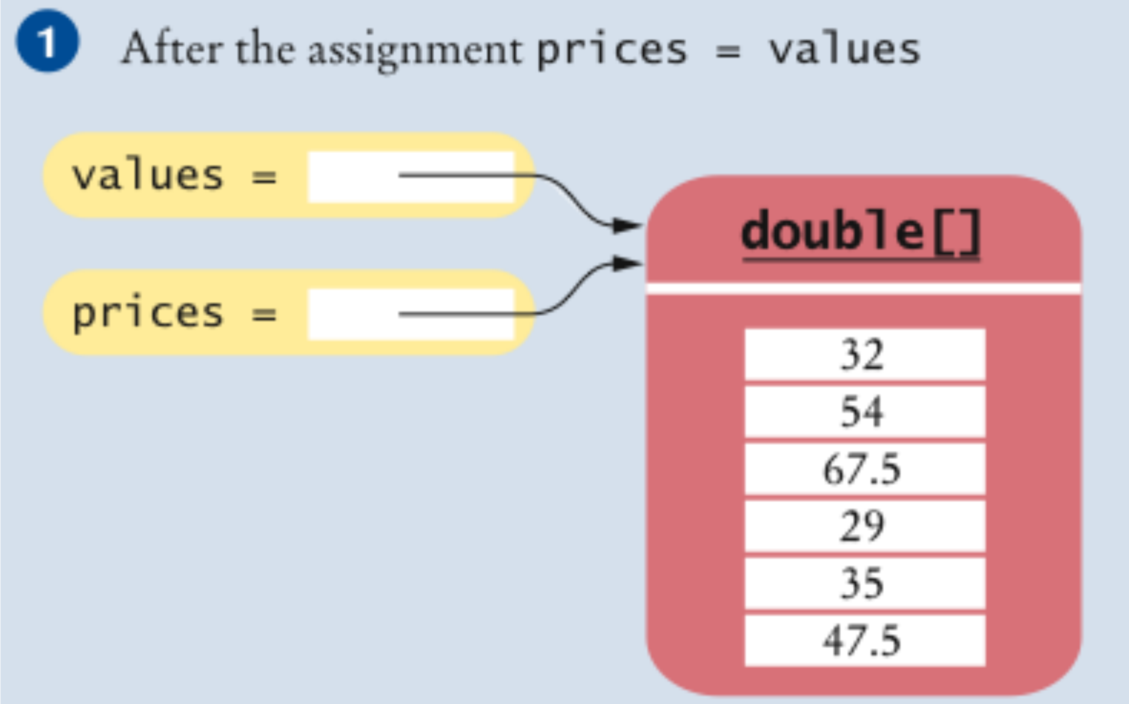
Elements are moved, starting from the removal location.

Removing from an 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; 1
```



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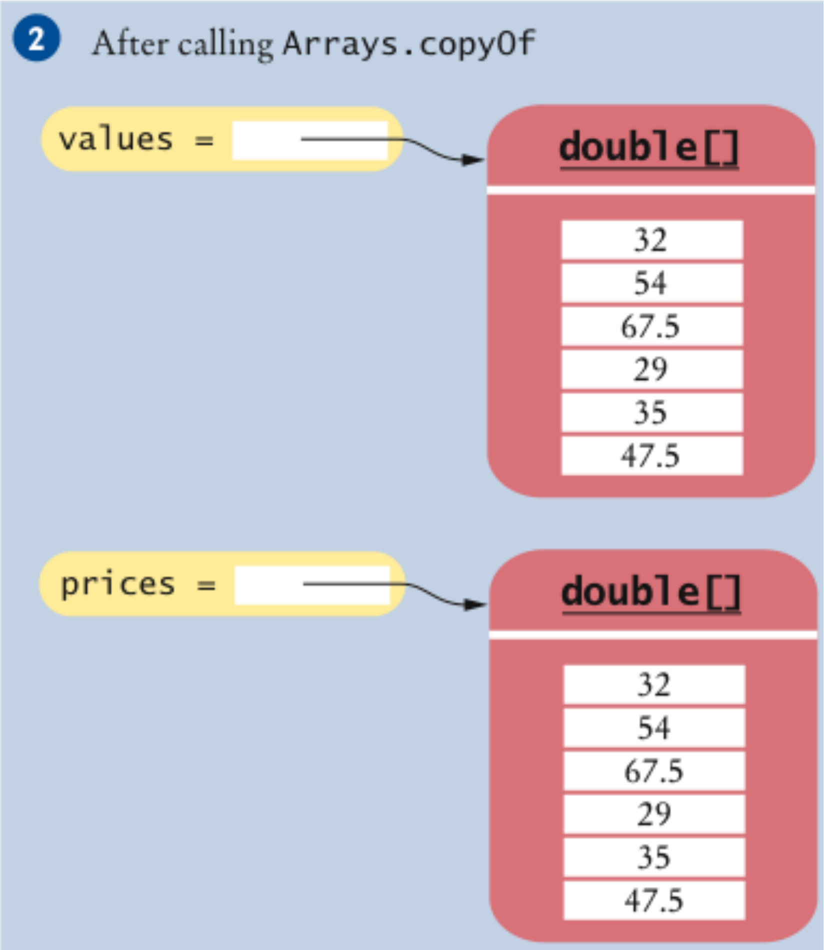
Common Array Algorithm: Copying an Array

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

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



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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);
```

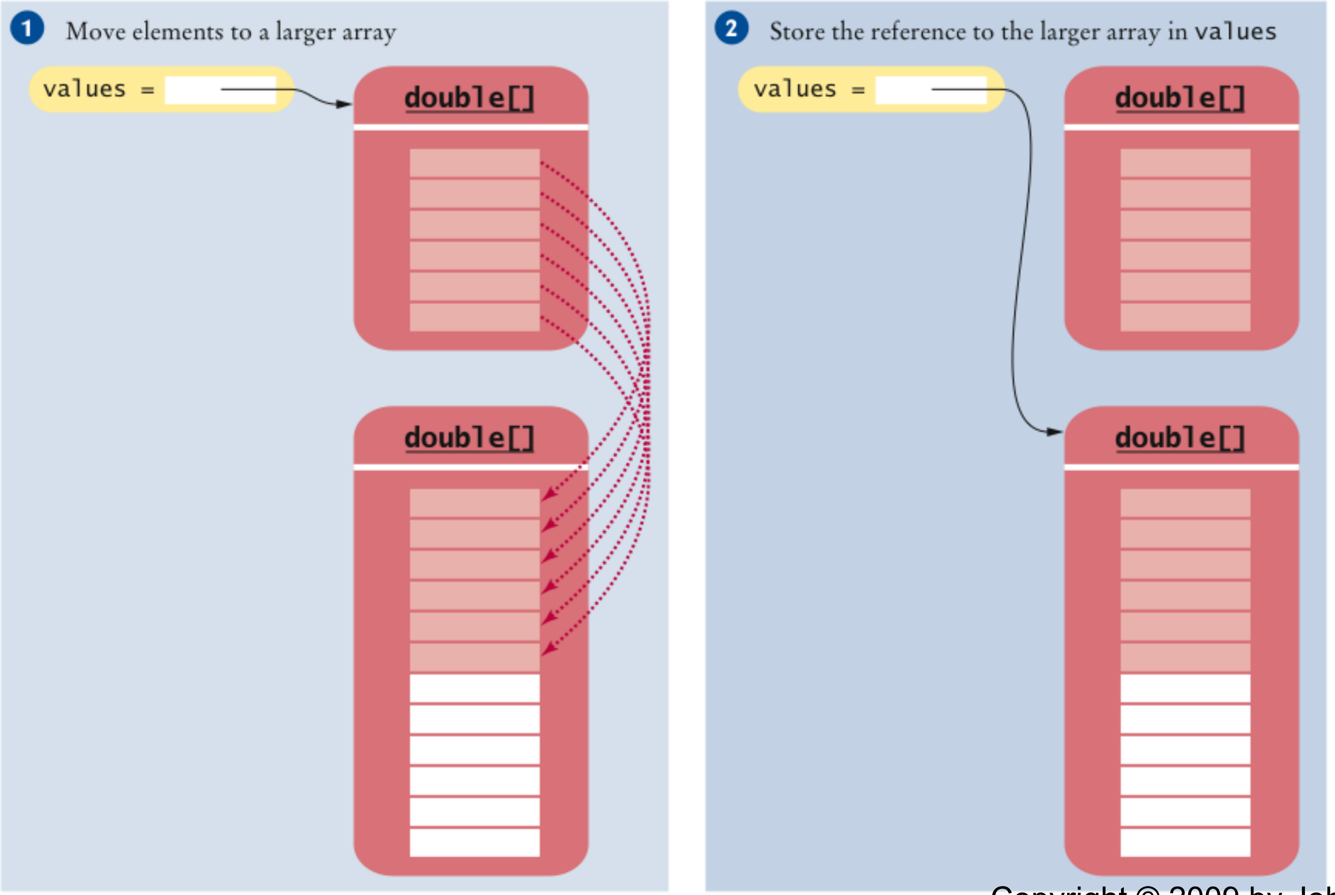
1
Move elements to a larger array
values =
double[]
double[]
2
Store the reference to the larger array in values
values =
double[]
double[]

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
```

- 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));
}
```

ch07/bank/Bank.java

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

```
import java.util.ArrayList;

/**
   This bank contains a collection of bank accounts.
*/
public class Bank
{
   private ArrayList<BankAccount> accounts;

   /**
      Constructs a bank with no bank accounts.
   */
   public Bank()
   {
      accounts = new ArrayList<BankAccount>();
   }
```

Continued

ch07/bank/Bank.java (cont.)

```
/**
   Adds an account to this bank.
   @param a the account to add
*/
public void addAccount(BankAccount a)
{
   accounts.add(a);
}

/**
   Gets the sum of the balances of all accounts in this bank.
   @return the sum of the balances
*/
public double getTotalBalance()
{
   double total = 0;
   for (BankAccount a : accounts)
   {
      total = total + a.getBalance();
   }
   return total;
}
```

Continued

ch07/bank/Bank.java (cont.)

```java
/**
   Counts the number of bank accounts whose balance is at
   least a given value.
   @param atLeast the balance required to count an account
   @return the number of accounts having least the given balance
*/
public int countBalancesAtLeast(double atLeast)
{
   int matches = 0;
   for (BankAccount a : accounts)
   {
      if (a.getBalance() >= atLeast) matches++; // Found a match
   }
   return matches;
}
```

Continued

ch07/bank/Bank.java (cont.)

```
/**
   Finds a bank account with a given number.
   @param accountNumber the number to find
   @return the account with the given number, or null if there
   is no such account
*/
public BankAccount find(int accountNumber)
{
  for (BankAccount a : accounts)
   {
      if (a.getAccountNumber() == accountNumber) // Found a match
         return a;
   }
   return null; // No match in the entire array list
}
```

Continued

ch07/bank/Bank.java (cont.)

```
   /**
      Gets the bank account with the largest balance.
      @return the account with the largest balance, or null if the
      bank has no accounts
   */
   public BankAccount getMaximum()
   {
      if (accounts.size() == 0) return null;
      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;
   }
}
```

ch07/bank/BankTester.java

```
/**
   This program tests the Bank class.
*/
public class BankTester
{
   public static void main(String[] args)
   {
      Bank firstBankOfJava = new Bank();
      firstBankOfJava.addAccount(new BankAccount(1001, 20000));
      firstBankOfJava.addAccount(new BankAccount(1015, 10000));
      firstBankOfJava.addAccount(new BankAccount(1729, 15000));

      double threshold = 15000;
      int count = firstBankOfJava.countBalancesAtLeast(threshold);
      System.out.println("Count: " + count);
      System.out.println("Expected: 2");
```

Continued

ch07/bank/BankTester.java (cont.)

```java
      int accountNumber = 1015;
      BankAccount account = firstBankOfJava.find(accountNumber);
      if (account == null)
         System.out.println("No matching account");
      else
         System.out.println("Balance of matching account: "
            + account.getBalance());
      System.out.println("Expected: 10000");

      BankAccount max = firstBankOfJava.getMaximum();
      System.out.println("Account with largest balance: "
            + max.getAccountNumber());
      System.out.println("Expected: 1001");
   }
}
```

Program Run:

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

Self Check 7.12

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 7.13

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

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

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Self Check 7.14

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 7.15

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

ch07/regression/BankTester.java

```java
import java.util.Scanner;

/**
   This program tests the Bank class.
*/
public class BankTester
{
   public static void main(String[] args)
   {
      Bank firstBankOfJava = new Bank();
      firstBankOfJava.addAccount(new BankAccount(1001, 20000));
      firstBankOfJava.addAccount(new BankAccount(1015, 10000));
      firstBankOfJava.addAccount(new BankAccount(1729, 15000));

      Scanner in = new Scanner(System.in);

      double threshold = in.nextDouble();
      int c = firstBankOfJava.count(threshold);
      System.out.println("Count: " + c);
      int expectedCount = in.nextInt();
      System.out.println("Expected: " + expectedCount);

```

Continued

ch07/regression/BankTester.java (cont.)

```java
      int accountNumber = in.nextInt();
      BankAccount a = firstBankOfJava.find(accountNumber);
      if (a == null)
         System.out.println("No matching account");
      else
      {
         System.out.println("Balance of matching account: " + a.getBalance());
         int matchingBalance = in.nextInt();
         System.out.println("Expected: " + matchingBalance);
      }
   }
}
```

Regression Testing: Input Redirection

- Store the inputs in a file
- ch07/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
```

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Self Check 7.16

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 7.17

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

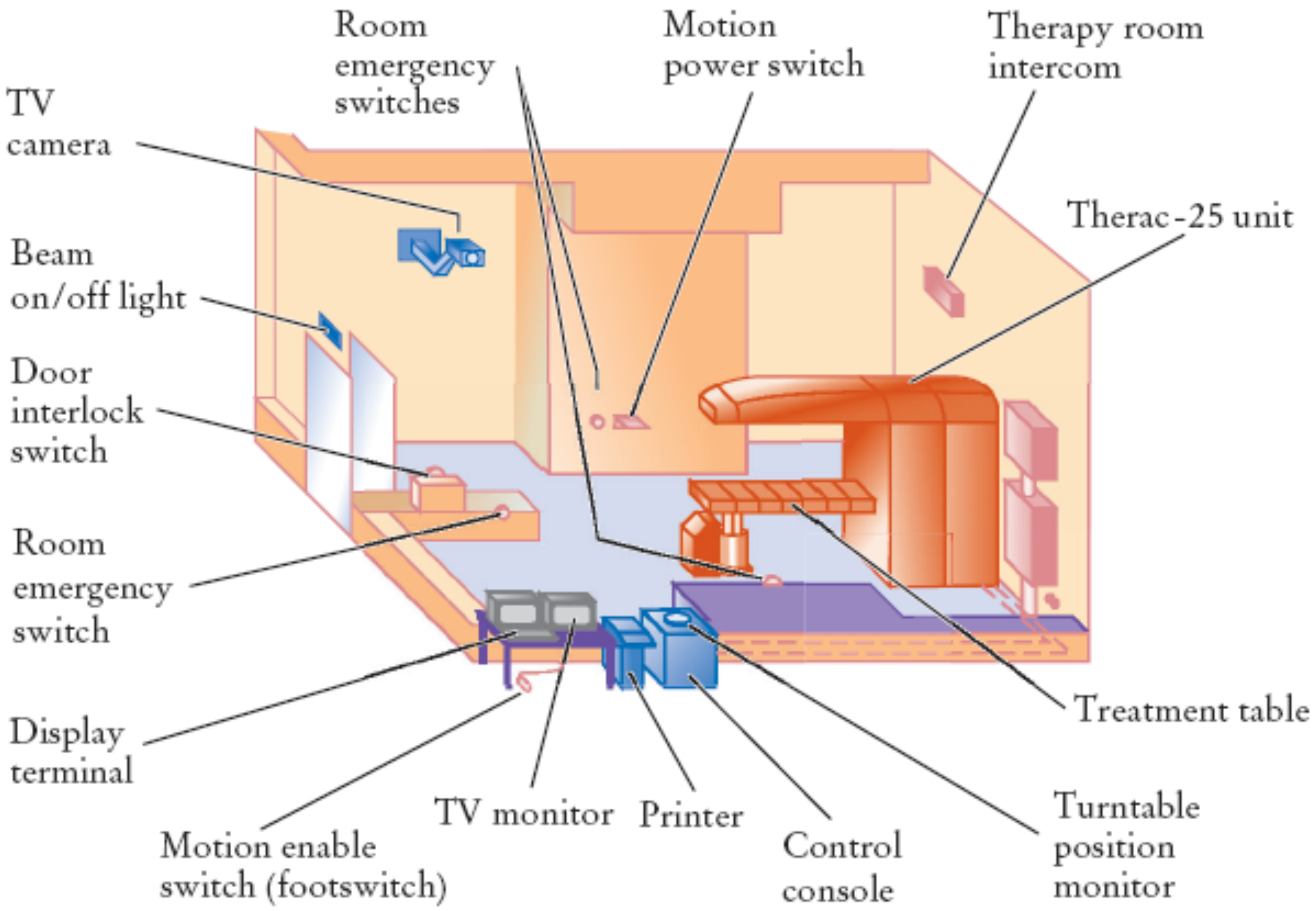
Answer: Add a test case to the test suite that verifies that the error is fixed.

Self Check 7.18

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

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Two-Dimensional Arrays

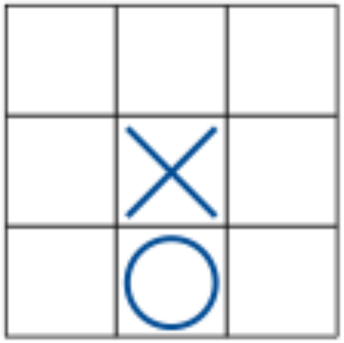

Figure 15 A Tic-Tac-Toe Board

- 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] = " ";
```

ch07/twodim/TicTacToe.java

```java
/**
   A 3 x 3 tic-tac-toe board.
*/
public class TicTacToe
{
   private String[][] board;
   private static final int ROWS = 3;
   private static final int COLUMNS = 3;

   /**
      Constructs an empty board.
   */
   public TicTacToe()
   {
      board = new String[ROWS][COLUMNS];
      // Fill with spaces
      for (int i = 0; i < ROWS; i++)
         for (int j = 0; j < COLUMNS; j++)
            board[i][j] = " ";
   }
```

Continued

ch07/twodim/TicTacToe.java (cont.)

```
/**
   Sets a field in the board. The field must be unoccupied.
   @param i the row index
   @param j the column index
   @param player the player ("x" or "o")
*/
public void set(int i, int j, String player)
{
   if (board[i][j].equals(" "))
      board[i][j] = player;
}
```

Continued

ch07/twodim/TicTacToe.java (cont.)

```
      Creates a string representation of the board, such as
      |x  o|
      | x |
      |  o|
      @return the string representation
   */
   public String toString()
   {
      String r = "";
      for (int i = 0; i < ROWS; i++)
      {
         r = r + "|";
         for (int j = 0; j < COLUMNS; j++)
            r = r + board[i][j];
         r = r + "|\n";
      }
      return r;
   }
}
```

ch07/twodim/TicTacToeRunner.java

```java
import java.util.Scanner;

/**
   This program runs a TicTacToe game. It prompts the
   user to set positions on the board and prints out the
   result.
*/
public class TicTacToeRunner
{
   public static void main(String[] args)
   {
      Scanner in = new Scanner(System.in);
      String player = "x";
      TicTacToe game = new TicTacToe();
```

Continued

ch07/twodim/TicTacToeRunner.java (cont.)

```
      boolean done = false;
      while (!done)
      {
         System.out.print(game.toString());
         System.out.print(
               "Row for " + player + " (-1 to exit): ");
         int row = in.nextInt();
         if (row < 0) done = true;
         else
         {
            System.out.print("Column for " + player + ": ");
            int column = in.nextInt();
            game.set(row, column, player);
            if (player.equals("x"))
               player = "o";
            else
               player = "x";
         }
      }
   }
}
```

ch07/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
```

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Self Check 7.19

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

Answer:

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

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Self Check 7.20

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++;
```