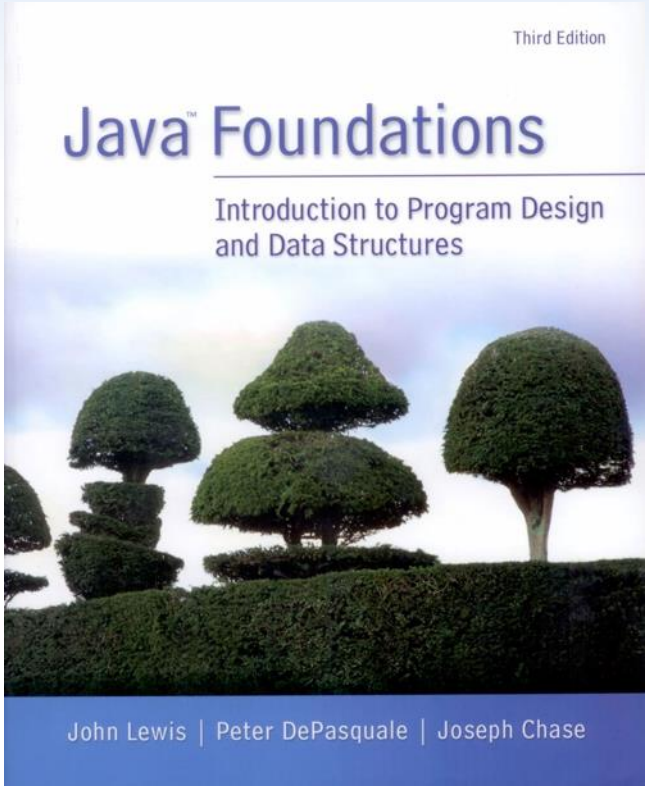


Chapter 7

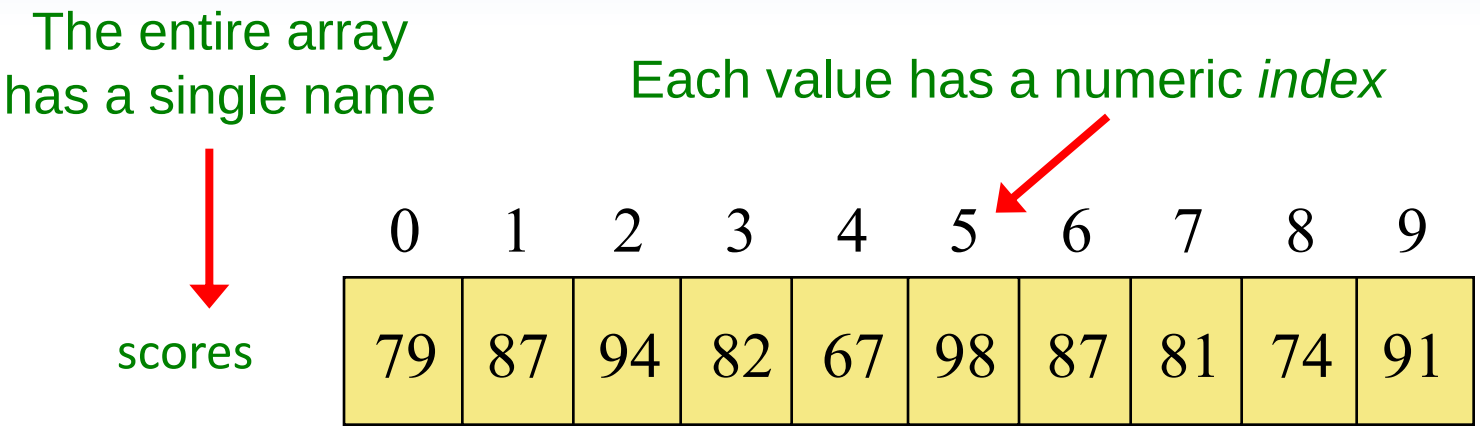
Arrays

Chapter Scope

- Array declaration and use
- Bounds checking
- Arrays as objects
- Arrays of objects
- Command-line arguments
- Variable-length parameter lists
- Multidimensional arrays

Arrays

- An *array* is an ordered list of values



An array of size N is indexed from zero to N-1

This array holds 10 values that are indexed from 0 to 9

Arrays

- A particular value in an array is referenced using the array name followed by the index in brackets
- For example, the expression

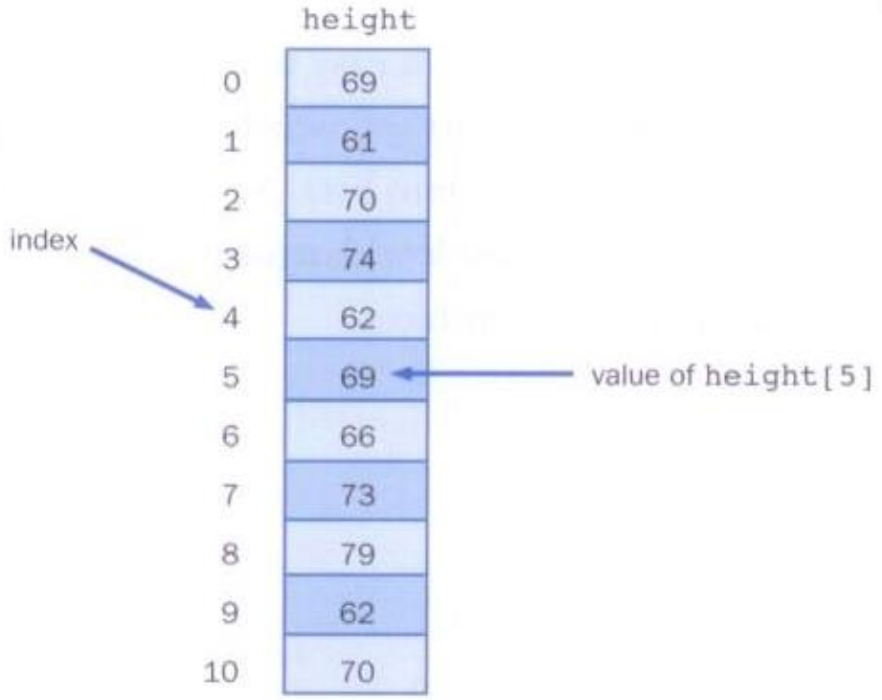
```
scores[2]
```

  refers to the value `94` (the 3rd value in the array)

- That expression represents a place to store a single integer and can be used wherever an integer variable can be used

Arrays

- Arrays can be depicted vertically or horizontally



Arrays

- An array element can be assigned a value, printed, or used in a calculation

```
scores[2] = 89;

scores[first] = scores[first] + 2;

mean = (scores[0] + scores[1])/2;

System.out.println("Top = " + scores[5]);
```

Arrays

- The values held in an array are called *array elements*
- An array stores multiple values of the same type – the *element type*
- The element type can be a primitive type or an object reference
- Therefore, we can create an array of integers, an array of characters, an array of `String` objects, an array of `Coin` objects, etc.
- In Java, the array itself is an object that must be instantiated

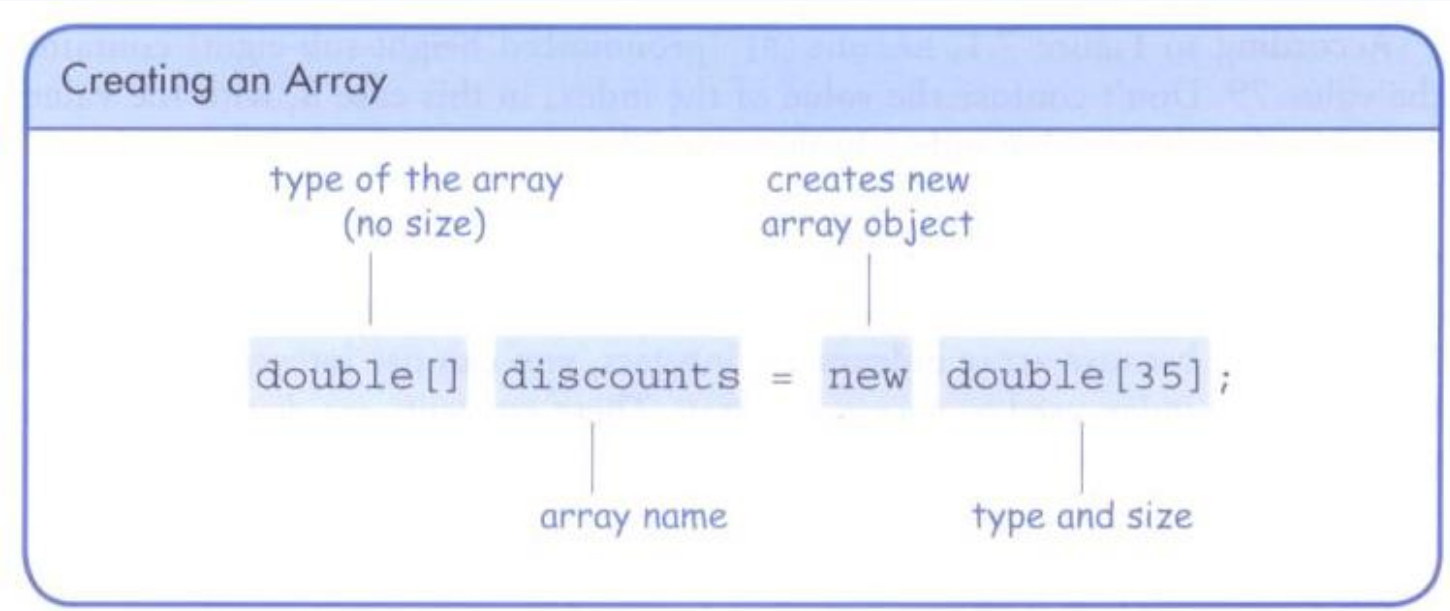
Declaring Arrays

- The `scores` array could be declared as follows

```
int[] scores = new int[10];
```

- The type of the variable `scores` is `int[]` (an array of integers)
- Note that the array type does not specify its size, but each object of that type has a specific size
- The reference variable `scores` is set to a new array object that can hold 10 integers

Declaring Arrays



Declaring Arrays

- Some other examples of array declarations

```
float[] prices = new float[500];

boolean[] flags;
flags = new boolean[20];

char[] codes = new char[1750];
```

Using Arrays

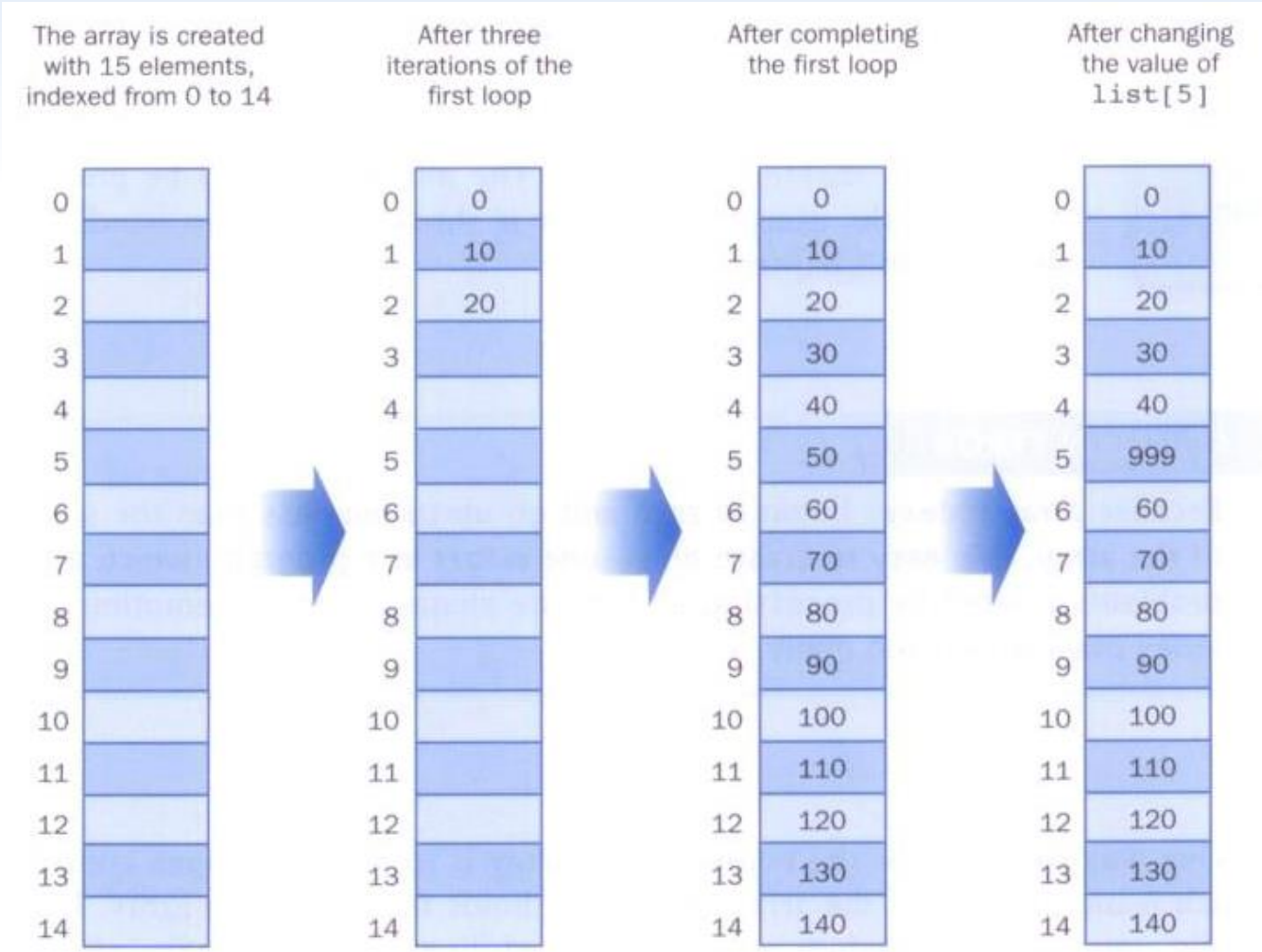
- The for-each loop can be used when processing array elements:

```
for (int score : scores)
   System.out.println(score);
```

- This is only appropriate when processing all array elements from the lowest index to the highest index

```
//********************************************************************
//  BasicArray.java       Java Foundations
//
//  Demonstrates basic array declaration and use.
//********************************************************************

public class BasicArray
{
   //-----------------------------------------------------------------
   //  Creates an array, fills it with various integer values,
   //  modifies one value, then prints them out.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      final int LIMIT = 15, MULTIPLE = 10;

      int[] list = new int[LIMIT];

      //  Initialize the array values
      for (int index = 0; index < LIMIT; index++)
         list[index] = index * MULTIPLE;

      list[5] = 999;  // change one array value

      //  Print the array values
      for (int value : list)
         System.out.print(value + "  ");
   }
}
```

BasicArray Example



Bounds Checking

- Once an array is created, it has a fixed size
- An index used in an array reference must specify a valid element
- That is, the index value must be in range 0 to N-1
- The Java interpreter throws an `ArrayIndexOutOfBoundsException` if an array index is out of bounds
- This is called automatic *bounds checking*

Bounds Checking

- For example, if the array `codes` can hold 100 values, it can be indexed using only the numbers 0 to 99

- If the value of `count` is 100, then the following reference will cause an exception to be thrown

```
System.out.println(codes[count]);
```

- It's common to introduce *off-by-one errors* when using arrays

problem

```
for (int index=0; index <= 100; index++)
   codes[index] = index*50 + epsilon;
```

Bounds Checking

- Each array object has a public constant called `length` that stores the size of the array
- It is referenced using the array name

```
scores.length
```

- Note that `length` holds the number of elements, not the largest index

```
//********************************************************************
//  ReverseOrder.java       Java Foundations
//
//  Demonstrates array index processing.
//********************************************************************

import java.util.Scanner;

public class ReverseOrder
{
   //-----------------------------------------------------------------
   //  Reads a list of numbers from the user, storing them in an
   //  array, then prints them in the opposite order.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      Scanner scan = new Scanner(System.in);

      double[] numbers = new double[10];

      System.out.println("The size of the array: " + numbers.length);

      for (int index = 0; index < numbers.length; index++)
      {
         System.out.print("Enter number " + (index+1) + ": ");
         numbers[index] = scan.nextDouble();
      }
```

```
      System.out.println("The numbers in reverse order:");

      for (int index = numbers.length-1; index >= 0; index--)
         System.out.print(numbers[index] + "  ");
   }
}
```

```
//********************************************************************
//  LetterCount.java       Java Foundations
//
//  Demonstrates the relationship between arrays and strings.
//********************************************************************

import java.util.Scanner;

public class LetterCount
{
   //-----------------------------------------------------------------
   //  Reads a sentence from the user and counts the number of
   //  uppercase and lowercase letters contained in it.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      final int NUMCHARS = 26;

      Scanner scan = new Scanner(System.in);

      int[] upper = new int[NUMCHARS];
      int[] lower = new int[NUMCHARS];

      char current;   // the current character being processed
      int other = 0;  // counter for non-alphabetics

      System.out.println("Enter a sentence:");
      String line = scan.nextLine();
```

```
      //  Count the number of each letter occurrence
      for (int ch = 0; ch < line.length(); ch++)
      {
         current = line.charAt(ch);
         if (current >= 'A' && current <= 'Z')
            upper[current-'A']++;
         else
            if (current >= 'a' && current <= 'z')
               lower[current-'a']++;
            else
               other++;
      }

      //  Print the results
      System.out.println ();
      for (int letter=0; letter < upper.length; letter++)
      {
         System.out.print((char) (letter + 'A'));
         System.out.print(": " + upper[letter]);
         System.out.print("\t\t" + (char) (letter + 'a'));
         System.out.println(": " + lower[letter]);
      }

      System.out.println();
      System.out.println("Non-alphabetic characters: " + other);
   }
}
```

Alternate Array Syntax

- The brackets of the array type can be associated with the element type or with the name of the array
- Therefore the following two declarations are equivalent

```
float[] prices;
float prices[];
```

- The first format generally is more readable and should be used

Initializer Lists

- An *initializer list* can be used to instantiate and fill an array in one step
- The values are delimited by braces and separated by commas
- Examples:

```
int[] units = {147, 323, 89, 933, 540,
               269, 97, 114, 298, 476};

char[] letterGrades = {'A', 'B', 'C', 'D', 'F'};
```

Initializer Lists

- Note that when an initializer list is used
  - the `new` operator is not used
  - no size value is specified
- The size of the array is determined by the number of items in the initializer list
- An initializer list can be used only in the array declaration

```
//********************************************************************
//  Primes.java       Java Foundations
//
//  Demonstrates the use of an initializer list for an array.
//********************************************************************

public class Primes
{
   //-----------------------------------------------------------------
   //  Stores some prime numbers in an array and prints them.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      int[] primeNums = {2, 3, 5, 7, 11, 13, 17, 19};

      System.out.println("Array length: " + primeNums.length);

      System.out.println("The first few prime numbers are:");

      for (int prime : primeNums)
         System.out.print(prime + "  ");
   }
}
```

Arrays as Parameters

- An entire array can be passed as a parameter to a method
- Like any other object, the reference to the array is passed, making the formal and actual parameters aliases of each other
- Therefore, changing an array element within the method changes the original
- An individual array element can be passed to a method as well, in which case the type of the formal parameter is the same as the element type

Arrays of Objects

- An array is an object and an array can hold objects as elements
- The array name is an object reference variable
- So this is another way to depict an array:

Arrays of Objects

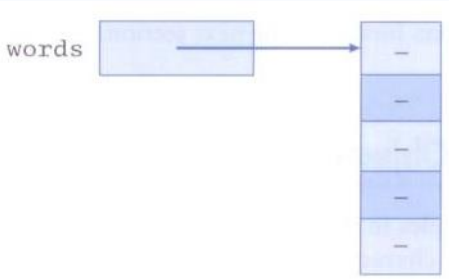
- An array of objects really holds object references
- The following declaration reserves space to store 5 references to `String` objects

```
String[] words = new String[5];
```

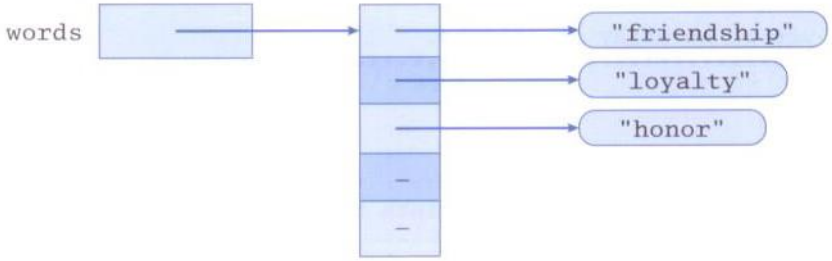
- It does not create the `String` objects themselves
- Initially an array of objects holds `null` references
- Each object stored in an array must be instantiated separately

Arrays of Objects

- After initial creation, an array holds null references:



- Each element is a reference to an object:



Arrays of Objects

- Keep in mind that `String` objects can be created using literals
- The following declaration creates an array object called `verbs` and fills it with four `String` objects created using string literals

```
String[] verbs = {"play", "work", "eat", "sleep"};
```

- The following example creates an array of `Grade` objects, each with a string representation and a numeric lower bound

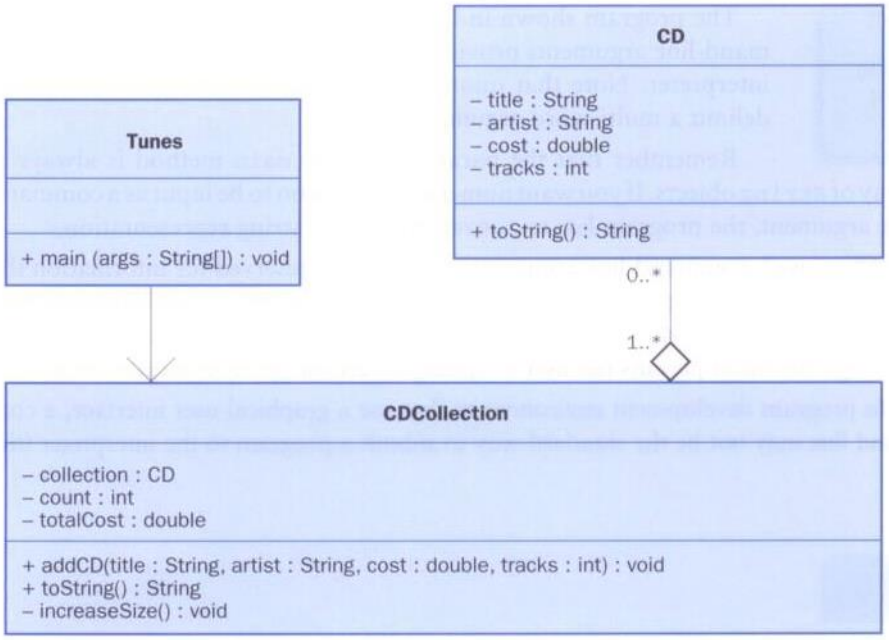
```
//********************************************************************
//  GradeRange.java       Java Foundations
//
//  Demonstrates the use of an array of objects.
//********************************************************************

public class GradeRange
{
   //-----------------------------------------------------------------
   //  Creates an array of Grade objects and prints them.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      Grade[] grades =
      {
         new Grade("A", 95), new Grade("A-", 90),
         new Grade("B+", 87), new Grade("B", 85), new Grade("B-", 80),
         new Grade("C+", 77), new Grade("C", 75), new Grade("C-", 70),
         new Grade("D+", 67), new Grade("D", 65), new Grade("D-", 60),
         new Grade("F", 0)
      };

      for (Grade letterGrade : grades)
         System.out.println(letterGrade);
   }
}
```

```
//********************************************************************
//  Grade.java       Java Foundations
//
//  Represents a school grade.
//********************************************************************

public class Grade
{
   private String name;
   private int lowerBound;

   //-----------------------------------------------------------------
   //  Constructor: Sets up this Grade object with the specified
   //  grade name and numeric lower bound.
   //-----------------------------------------------------------------
   public Grade(String grade, int cutoff)
   {
      name = grade;
      lowerBound = cutoff;
   }

   //-----------------------------------------------------------------
   //  Returns a string representation of this grade.
   //-----------------------------------------------------------------
   public String toString()
   {
      return name + "\t" + lowerBound;
   }
```

```
   //-----------------------------------------------------------------
   //  Name mutator.
   //-----------------------------------------------------------------
   public void setName(String grade)
   {
      name = grade;
   }

   //-----------------------------------------------------------------
   //  Lower bound mutator.
   //-----------------------------------------------------------------
   public void setLowerBound(int cutoff)
   {
      lowerBound = cutoff;
   }

   //-----------------------------------------------------------------
   //  Name accessor.
   //-----------------------------------------------------------------
   public String getName()
   {
      return name;
   }

   //-----------------------------------------------------------------
   //  Lower bound accessor.
   //-----------------------------------------------------------------
   public int getLowerBound()
   {
      return lowerBound;
   }
}
```

Arrays of Objects

- Now let's look at an example that stores a collection of `CD` objects



```
//********************************************************************
//  Tunes.java       Java Foundations
//
//  Demonstrates the use of an array of objects.
//********************************************************************

public class Tunes
{
   //-----------------------------------------------------------------
   //  Creates a CDCollection object and adds some CDs to it. Prints
   //  reports on the status of the collection.
   //-----------------------------------------------------------------
   public static void main (String[] args)
   {
      CDCollection music = new CDCollection ();

      music.addCD("Storm Front", "Billy Joel", 14.95, 10);
      music.addCD("Come On Over", "Shania Twain", 14.95, 16);
      music.addCD("Soundtrack", "Les Miserables", 17.95, 33);
      music.addCD("Graceland", "Paul Simon", 13.90, 11);

      System.out.println(music);

      music.addCD("Double Live", "Garth Brooks", 19.99, 26);
      music.addCD("Greatest Hits", "Jimmy Buffet", 15.95, 13);

      System.out.println(music);
   }
}
```

```
//********************************************************************
//  CDCollection.java       Java Foundations
//
//  Represents a collection of compact discs.
//********************************************************************

import java.text.NumberFormat;

public class CDCollection
{
   private CD[] collection;
   private int count;
   private double totalCost;

   //-----------------------------------------------------------------
   //  Constructor: Creates an initially empty collection.
   //-----------------------------------------------------------------
   public CDCollection()
   {
      collection = new CD[100];
      count = 0;
      totalCost = 0.0;
   }
```

```
//-----------------------------------------------------------------
//  Adds a CD to the collection, increasing the size of the
//  collection if necessary.
//-----------------------------------------------------------------
public void addCD(String title, String artist, double cost,
                  int tracks)
{
   if (count == collection.length)
      increaseSize();

   collection[count] = new CD(title, artist, cost, tracks);
   totalCost += cost;
   count++;
}
```

```
//-----------------------------------------------------------------
//  Returns a report describing the CD collection.
//-----------------------------------------------------------------
public String toString()
{
   NumberFormat fmt = NumberFormat.getCurrencyInstance();

   String report = "~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~\n";
   report += "My CD Collection\n\n";

   report += "Number of CDs: " + count + "\n";
   report += "Total cost: " + fmt.format(totalCost) + "\n";
   report += "Average cost: " + fmt.format(totalCost/count);

   report += "\n\nCD List:\n\n";

   for (int cd = 0; cd < count; cd++)
      report += collection[cd].toString() + "\n";

   return report;
}
```

```
   //-----------------------------------------------------------------
   //  Increases the capacity of the collection by creating a
   //  larger array and copying the existing collection into it.
   //-----------------------------------------------------------------
   private void increaseSize()
   {
      CD[] temp = new CD[collection.length * 2];

      for (int cd = 0; cd < collection.length; cd++)
         temp[cd] = collection[cd];

      collection = temp;
   }
}
```

```
//********************************************************************
//  CD.java       Java Foundations
//
//  Represents a compact disc.
//********************************************************************

import java.text.NumberFormat;

public class CD
{
   private String title, artist;
   private double cost;
   private int tracks;

   //-----------------------------------------------------------------
   //  Creates a new CD with the specified information.
   //-----------------------------------------------------------------
   public CD(String name, String singer, double price, int numTracks)
   {
      title = name;
      artist = singer;
      cost = price;
      tracks = numTracks;
   }
```

```
   //-----------------------------------------------------------------
   //  Returns a string description of this CD.
   //-----------------------------------------------------------------
   public String toString()
   {
      NumberFormat fmt = NumberFormat.getCurrencyInstance();

      String description;

      description = fmt.format(cost) + "\t" + tracks + "\t";
      description += title + "\t" + artist;

      return description;
   }
}
```

Command-Line Arguments

- The signature of the `main` method indicates that it takes an array of `String` objects as a parameter
- These values come from *command-line arguments* that are provided when the interpreter is invoked
- For example, the following invocation of the interpreter passes three `String` objects into `main`

```
> java StateEval pennsylvania texas arizona
```

- These strings are stored at indexes 0-2 of the array parameter of the `main` method

```
//********************************************************************
//  CommandLine.java       Java Foundations
//
//  Demonstrates the use of command line arguments.
//********************************************************************

public class CommandLine
{
   //-----------------------------------------------------------------
   //  Prints all of the command line arguments provided by the
   //  user.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      for (String arg : args)
         System.out.println(arg);
   }
}
```

Variable Length Parameter Lists

- Suppose we wanted to create a method that processed a different amount of data from one invocation to the next
- For example, let's define a method called `average` that returns the average of a set of integer parameters

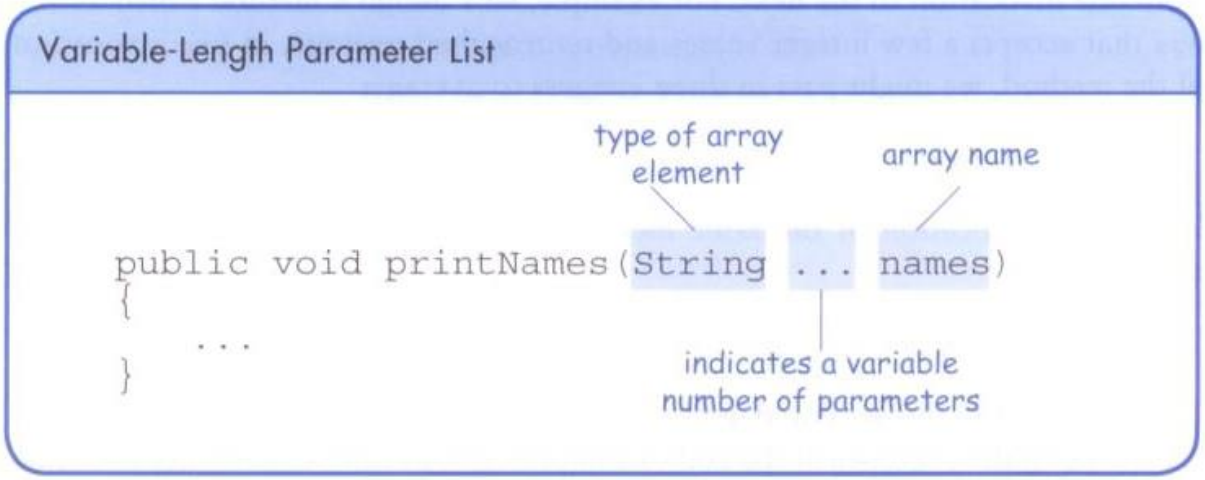
```
// one call to average three values
mean1 = average (42, 69, 37);

// another call to average seven values
mean2 = average (35, 43, 93, 23, 40, 21, 75);
```

Variable Length Parameter Lists

- We could define overloaded versions of the `average` method
  - Downside: we'd need a separate version of the method for each parameter count
- We could define the method to accept an array of integers
  - Downside: we'd have to create the array and store the integers prior to calling the method each time
- Instead, Java provides a convenient way to create *variable length parameter lists*

Variable Length Parameter Lists

- Using special syntax in the formal parameter list, we can define a method to accept any number of parameters of the same type
- For each call, the parameters are automatically put into an array for easy processing in the method



Variable Length Parameter Lists

```
public double average(int ... list)
{
   double result = 0.0;

   if (list.length != 0)
   {
      int sum = 0;
      for (int num : list)
         sum += num;
      result = (double)num / list.length;
   }

   return result;
}
```

Variable Length Parameter Lists

- The type of the parameter can be any primitive or object type

```
public void printGrades(Grade ... grades)
{
   for (Grade letterGrade : grades)
      System.out.println (letterGrade);
}
```

Variable Length Parameter Lists

- A method that accepts a variable number of parameters can also accept other parameters

- The following method accepts an `int`, a `String` object, and a variable number of `double` values into an array called `nums`

```
public void test(int count, String name,
                 double ... nums)
{
   // whatever
}
```

Variable Length Parameter Lists

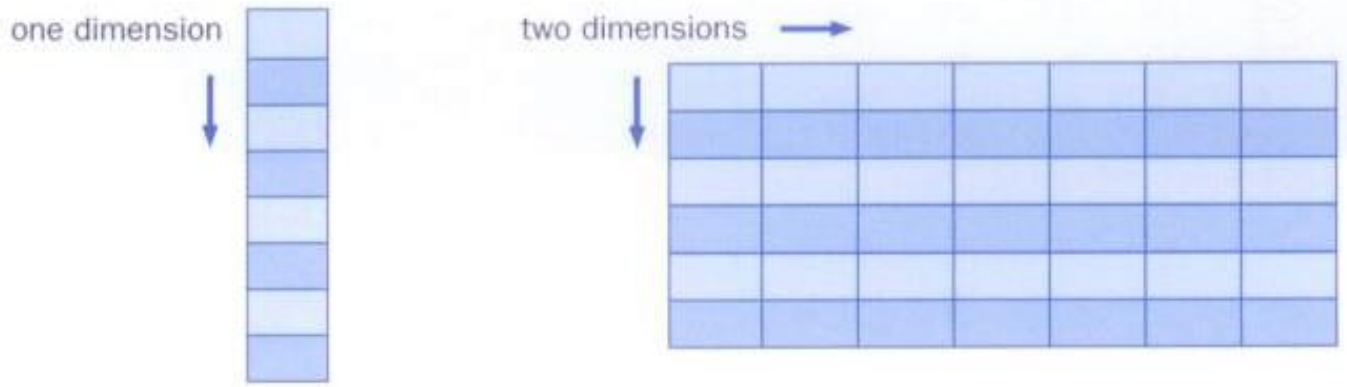
- The varying number of parameters must come last in the formal arguments
- A single method cannot accept two sets of varying parameters
- Constructors can also be set up to accept a variable number of parameters

```
//********************************************************************
//  VariableParameters.java       Java Foundations
//
//  Demonstrates the use of a variable length parameter list.
//********************************************************************

public class VariableParameters
{
   //-----------------------------------------------------------------
   //  Creates two Family objects using a constructor that accepts
   //  a variable number of String objects as parameters.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      Family lewis = new Family("John", "Sharon", "Justin", "Kayla",
         "Nathan", "Samantha");

      Family camden = new Family("Stephen", "Annie", "Matt", "Mary",
         "Simon", "Lucy", "Ruthie", "Sam", "David");

      System.out.println(lewis);
      System.out.println();
      System.out.println(camden);
   }
}
```

```
//********************************************************************
//  Family.java       Java Foundations
//
//  Demonstrates the use of variable length parameter lists.
//********************************************************************

public class Family
{
   private String[] members;

   //-----------------------------------------------------------------
   //  Constructor: Sets up this family by storing the (possibly
   //  multiple) names that are passed in as parameters.
   //-----------------------------------------------------------------
   public Family(String ... names)
   {
      members = names;
   }

   //-----------------------------------------------------------------
   //  Returns a string representation of this family.
   //-----------------------------------------------------------------
   public String toString()
   {
      String result = "";

      for (String name : members)
         result += name + "\n";

      return result;
   }
}
```

Two-Dimensional Arrays

- A *one-dimensional array* stores a list of elements
- A *two-dimensional array* can be thought of as a table of elements, with rows and columns



Two-Dimensional Arrays

- To be precise, in Java a two-dimensional array is an array of arrays
- A two-dimensional array is declared by specifying the size of each dimension separately

```
int[][] scores = new int[12][50];
```

- A array element is referenced using two index values

```
value = scores[3][6]
```

- The array stored in one row can be specified using one index

```
//********************************************************************
//  TwoDArray.java       Java Foundations
//
//  Demonstrates the use of a two-dimensional array.
//********************************************************************

public class TwoDArray
{
   //-----------------------------------------------------------------
   //  Creates a 2D array of integers, fills it with increasing
   //  integer values, then prints them out.
   //-----------------------------------------------------------------
   public static void main(String[] args)
   {
      int[][] table = new int[5][10];

      // Load the table with values
      for (int row=0; row < table.length; row++)
         for (int col=0; col < table[row].length; col++)
            table[row][col] = row * 10 + col;

      // Print the table
      for (int row=0; row < table.length; row++)
      {
         for (int col=0; col < table[row].length; col++)
            System.out.print(table[row][col] + "\t");
         System.out.println();
      }
   }
}
```

Two-Dimensional Arrays

Expression	Type	Description
`table`	`int[][]`	2D array of integers, or array of integer arrays
`table[5]`	`int[]`	array of integers
`table[5][12]`	`int`	integer

```
//********************************************************************
//  SodaSurvey.java       Java Foundations
//
//  Demonstrates the use of a two-dimensional array.
//********************************************************************

import java.text.DecimalFormat;

public class SodaSurvey
{
   //-----------------------------------------------------------------
   //  Determines and prints the average of each row (soda) and each
   //  column (respondent) of the survey scores.
   //-----------------------------------------------------------------
   public static void main (String[] args)
   {
      int[][] scores = { {3, 4, 5, 2, 1, 4, 3, 2, 4, 4},
                         {2, 4, 3, 4, 3, 3, 2, 1, 2, 2},
                         {3, 5, 4, 5, 5, 3, 2, 5, 5, 5},
                         {1, 1, 1, 3, 1, 2, 1, 3, 2, 4} };

      final int SODAS = scores.length;
      final int PEOPLE = scores[0].length;

      int[] sodaSum = new int[SODAS];
      int[] personSum = new int[PEOPLE];
```

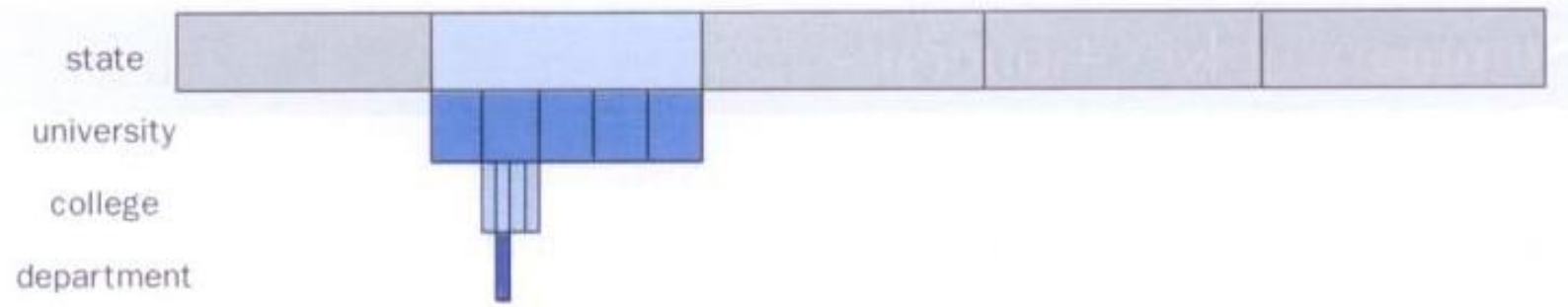
```
      for (int soda=0; soda < SODAS; soda++)
         for (int person=0; person < PEOPLE; person++)
         {
            sodaSum[soda] += scores[soda][person];
            personSum[person] += scores[soda][person];
         }

      DecimalFormat fmt = new DecimalFormat("0.#");
      System.out.println("Averages:\n");

      for (int soda=0; soda < SODAS; soda++)
         System.out.println("Soda #" + (soda+1) + ": " +
                     fmt.format((float)sodaSum[soda]/PEOPLE));

      System.out.println ();
      for (int person=0; person < PEOPLE; person++)
         System.out.println("Person #" + (person+1) + ": " +
                     fmt.format((float)personSum[person]/SODAS));
   }
}
```

Multidimensional Arrays

- Any array with more than one dimension is a *multidimensional array*
- Each dimension subdivides the previous one into the specified number of elements
- Each dimension has its own `length` constant
- Because each dimension is an array of array references, the arrays within one dimension can be of different lengths
  - these are sometimes called *ragged arrays*

Multidimensional Arrays

- One way to visualize a four-dimensional array:



- Two-dimensional arrays are common, but beyond that usually an array has other objects involved