

## CS A201

### Arrays

Say you want to keep an inventory of items. Based on what we have covered so far, you have to create a separate variable for each one:

```
int numItem1;  
int numItem2;  
int numItem3;
```

etc.

This works fine, but what if you had hundreds of items? It would be too much work to explicitly declare each one. It would be nice if we could programmatically access each separate variable. The construct that allows us to do this is called an **array**. We will first examine one-dimensional arrays, and then proceed to multi-dimensional arrays.

An array is a consecutive group of memory locations that all have the same name and the same type. To refer to a particular location, we specify the name and then the positive index into the array. The index is specified by square brackets, []. The first index is 0. The format for defining an array is:

```
Type[] varName = new Type[Size];
```

For example, let's say we define an array of type **byte** of size six:

```
byte[] a = new byte[6];
```

This allocates in the computer 6 bytes for the array: These bytes are stored somewhere in memory, let's say they are stored at memory address X, where let's say X is at 1000:

Memory Address	Array Index	Contents
X, e.g. 1000	a[0]	0
X+1, e.g. 1001	a[1]	0
X+2, e.g. 1002	a[2]	0
X+3, e.g. 1003	a[3]	0
X+4, e.g. 1004	a[4]	0
X+5, e.g. 1005	a[5]	0

Initially the contents of the array variables are set to zero.

How does the computer know how much memory to allocate to each array element? It allocates enough memory to hold the size of the data type the array is defined for. Since Java allocates 4 bytes for an integer, and we define our array as:

```
int[] a = new int[6];
```

This results in memory allocation:

Memory Address	Array Index	Contents
X, e.g. 1000	a[0]	0
X+4, e.g. 1004	a[1]	0
X+8, e.g. 1008	a[2]	0
X+12, e.g. 1012	a[3]	0
X+16, e.g. 1016	a[4]	0
X+20, e.g. 1020	a[5]	0

We can refer to the array like we have defined six variables. a[0] refers to the first variable in the array. Note that if we try to access a[6] in this case, then we will be trying to access memory location X+24. This will be exceeding the bounds of the array, and will generate a Java runtime error (programming languages that aren't interpreted generally don't catch this error, resulting in bugs where we may be accessing memory we aren't supposed to!).

Here are some simple ways we can access the array just like it was a variable:

```
a[3] = 54; // Stores 54 into array element 3
a[0] = a[3]; // Copies 54 into array element 0
a[5] = a[2+1]; // Copies contents of a[3] to a[5]
i=5;
a[i]++; // Increment value in a[5]

for (i=0;i<6; i++)
    System.out.println(a[i]); // Print each array element
```

**Note that if we use:**

```
System.out.println(a);
```

**where a is an array, we do NOT print out each element.** Instead the computer will print out the memory address where the array is stored. This is probably not what you want; to print out all array elements, we need to individually print each one in a loop. An array is actually a class object, and as we saw earlier class objects are stored as a reference to the memory address where the object is located.

The flexible thing here is we can programmatically access each variable, based on the index, instead of hard-coding the access by hand.

To initialize an array, we could use a loop as above:

```
int[] a = new int[6];
int j;
for (j=0; j<6; j++)
    a[j]=99;
```

We can also use initializers for arrays. To define an array and initialize it at the same time, we can use curly braces { } :

```
int[] a = {1, 2, 3, 4, 5, 6};
```

This sets a[0] to 1, a[1] to 2, a[2] to 3, a[3] to 4, a[4] to 5, and a[5] to 6. Since we are initializing the array with six elements, the compiler knows to make the size of the array six.

An equivalent way to initialize the same array is to use:

```
int[] a = new int[6];
a[0]=1; a[1]=2; a[2]=3; a[3]=4; a[4]=5; a[5]=6;
```

A good programming technique when using arrays is to define some constant for the array size. This has the benefit that if you ever need to change the size of the array, you can do it in one place. If you hardcoded a number like “6” into the program, then there may be many places you need to change:

```
public static final int ARRAYSIZE = 6;
...
int[] a = new int[ARRAYSIZE], j;
for (j=0; j<ARRAYSIZE; j++)
{
    a[j]=j;
}
```

Let's look at a few example programs that use arrays. The first one inputs 10 numbers from the user and then calculates the average:

```
private static final int ARRAYSIZE = 10;
public static void main(String[] args)
{
    int[] n = new int[ARRAYSIZE];
    int i=0, total=0;
    Scanner keyboard = new Scanner(System.in);

    for (i=0; i<ARRAYSIZE; i++)
    {
        System.out.println("Enter a number. ");
        n[i] = keyboard.nextInt();
    }
    for (i=0; i<ARRAYSIZE; i++)
    {
        total += n[i];
    }
    System.out.println("The average is : " + total/ARRAYSIZE);
}
```

In this example, we loop over the array twice. Once to input each value, and another time to generate the average. Note that we could compute the average while also entering the numbers, if we wished. What would happen if the first for loop had “<=” instead of “<” ?

## Arrays Are Objects

An array is a type of object, and like other objects it has methods and instance variables. Some of these methods include “equals()”, “clone()”, and “toString()” which we will discuss later. For now, a useful variable is “length” which is equal to the size of the array. For example, in the previous case, we could use the following:

```
for (i=0; i < n.length; i++)
{
    . . .
}
```

Also, since arrays are objects, this means we can't use == to compare two arrays to see if they are equal. Instead, this will compare their memory addresses instead of the contents of the array.

To see if two arrays are equal, you must use something that compares every element, e.g.:

```
// First, assume the arrays are equal
if (a.length != b.length)
{
    // not equal
}
for (i=0; i < a.length; i++)
{
    if (a[i]!=b[i])
    {
        // not equal
    }
}
```

If you import `java.util.Arrays` then you may use `Arrays.equals(arr1, arr2)` to see if two arrays are identical (there is also a `deepEquals` which determines if sub-objects in the arrays are also equal).

Also, we can't use the assignment operator to set one array equal to another if we wish to copy the contents of one array to another. The assignment:

```
b = a;
```

Will instead set variable `b` to the same memory address as `a`. For example, consider the following code snippet:

```

int[] a = new int[3];
int[] b = new int[3];

a[0]=1; a[1]=1; a[2]=1;
b[0]=0; b[1]=0; b[2]=0;
System.out.println(a[0] + " " + b[0]);    // 1 0
b = a;
System.out.println(a[0] + " " + b[0]);    // 1 1
a[0]=9;
System.out.println(a[0] + " " + b[0]);    // 9 9

```

The first two print statements behave as expected. However, the last print statement outputs that `b[0]` is equal to 9! This is because in setting “`b=a`” we are setting `b` to point to the same memory address where `a` is stored. Then, when we set “`a[0]=9`”, when we dereference array `b`, we get back the new value for `a`.

To copy one array to another we should copy each element individually, e.g.:

```

for (i=0; i < b.length; i++)
{
    a[i]=b[i];
}

```

The `clone()` method can also be used to make an identical copy of an array, to get the same effect more easily:

```

b = a.clone();

```

Array `b` is now set to a copy of array `s`.

## Two-Dimensional Arrays

A two-dimensional array is a collection of data of the same type that is structured in two dimensions. Individual variables are accessed by their position within each dimension. You can think of a 2-D array as a table of a particular data type. The following example creates a 2-D array of type `int`:

```

int[][] twoDimAry = new int[5][10];

```

`twoDimAry` is an array variable that has 5 rows and 10 columns. Each row and column entry is of type `int`. The following code fragment sets all the entries in `twoDimAry` to 0:

```

for (int column = 0; column < 10; column++)
    for(int row = 0; row < 5; row++)
        twoDimAry[row][column] = 0;

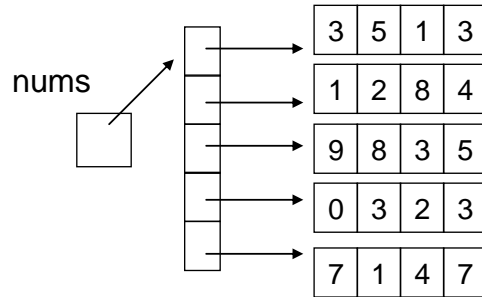
```

Processing a two-dimensional array variable requires two loops: one for the rows and one for the columns. If the outer loop is the index for the column, the array is processed by

column. If the outer loop is the index for the row, the array is processed by row. The preceding loop processes twoDimAry by columns.

Internally, Java really stores 2D arrays as an array of arrays. For example:

```
int [][] nums = new int[5][4];
```



This organization can be a bit inefficient, but allows for “ragged” arrays where the size of the second dimension varies from row to row.

## Multidimensional Arrays

You have seen one-dimensional and two-dimensional arrays. In Java, arrays may have any number of dimensions. To process every item in a one-dimensional array, you need one loop. To process every item in a two-dimensional array, you need two loops. The pattern continues to any number of dimensions. To process every item in an n-dimensional array, you need n loops.

For example, if we wanted to declare an array of 3 dimensions, each with 10 elements, we could do so via;

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

## Passing Arrays To Methods

If passing a single value inside an array as a parameter to a method, this is done exactly as we have covered before. The index of an array is a variable, and we are then passing just that variable. For example, the following code outputs 2:

```
public static void main(String[] argv)
{
    int[] arr = {1, 2, 3};
    MyFunc(arr[1]);
}

public static void MyFunc(int x)
{
    System.out.println(x); // Outputs 2
}
```

When an entire array is passed as a parameter to a method, specify the name of the array without any brackets in the method call. In the heading of the method definition we should include the brackets, but it is not necessary to specify the length of the array. For example, the following illustrates passing a single one-dimensional array to a function:

```
public static void main(String[] argv)
{
    int[] arr = {1, 2, 3};
    MyFunc(arr);
}

public static void MyFunc(int[] x)
{
    System.out.println(x[1]); // Outputs 2
}
```

Since arrays are objects, they are passed by reference. This means that if we change the contents of the array inside MyFunc, the changes will be reflected back in arr inside main. One reason for this is efficiency – if arrays were passed by value, it would mean copying the entire contents of the array on the stack. If the array was very large, this would take a long time. In the following example, the function changes array element 0 to 10, and this change will be reflected in main.

```
public static void main(String[] argv)
{
    int[] arr = {1, 2, 3};
    MyFunc(arr);
    System.out.println(arr[0] + " " + arr[1] + " " + arr[2]);
}

public static void MyFunc(int[] x)
{
    System.out.println(x[1]);
    x[0] = 10;
}
```

This code outputs:

```
2
10 2 3
```

What actually happens is that using the array variable without any brackets is really a pointer to the place in memory when the array is stored. This has implications later, but for passing the array as a parameter, it means we're really passing a pointer to the place where the data is stored. We follow the pointer inside the function to change the contents of the source array.

If we are passing a multidimensional array, we would simply use the proper number of []'s that match the size of the array.

## Returning Arrays From Methods

A method may also return an array, much like we would return any other value. To do so, we indicate that the return type is an array by using the square brackets. Here is an example that takes an input String and returns an array histogram:

```
public class ArrayExample
{
    public static void main(String[] argv)
    {
        String s;
        int i;
        int[] histogram;

        s = "The quick brown fox jumps over the lazy dog";
        histogram = ComputeLetterHistogram(s);
        for (i=0; i<histogram.length; i++)
        {
            Character c = new Character((char) (i+'A'));
            System.out.println("The letter " + c.toString()
                + " appeared " + histogram[i] + " times.");
        }
    }

    public static int[] ComputeLetterHistogram(String s)
    {
        int i;
        int[] histo = new int[26];
        String s2;
        char c;
        // Initialize histogram to zero
        for (i=0; i<26; i++)
            histo[i]=0;

        s2 = s.toUpperCase();
        // Count how many times each letter appears in array
        for (i=0; i<s2.length(); i++)
        {
            c = s2.charAt(i);
            if ((c >= 'A') && (c <= 'Z'))
                histo[c-'A']++;
        }
        return histo;
    }
}
```

The output of this program is a count of how many times each letter appears (case notwithstanding). There are a couple of issues to note here:

- There is no “new” used when we define histogram in main. This is because we don’t need to actually create the object and allocate memory for it here – we are allocating the memory for it inside ComputeLetterHistogram and returning the object.



- ‘A’ by itself refers to the ASCII code for the letter A (65). So “i+’A’” really is the same as “i+65” but it is often more convenient to use ‘A’ instead of the ASCII number to keep things straight. 65+1 or 66 is the letter ‘B’, 67 is the letter ‘C’, etc. Similarly, “c-‘A’” computes the value 0 for ‘A’, 1 for ‘B’, 2 for ‘C’, etc.
- The Character class is used to convert from an ASCII code to an actual character. This character is then converted to a string when we print it out.

### Array/Method Exercise:

Write a program that inputs 10 integer, numeric grades into an array and finds the average and the max. Write main and the following three functions:

```
public static void inputNumbers(int grades[]);
public static int findMax(int grades[]);
public static int findAverage(int grades[]);
```

### Array Example – Trivia Game

Let’s write a program to play a simple trivia game. First we need a database of trivia questions. For simplicity, let’s make our game have five questions. Each question has a correct answer and a point value. In the game we’ll ask each question to the player and calculate the total score.

Our strategy will be to create three arrays, each with five elements. The first array will hold the questions, the second array will hold the answers, and the third array will hold the value. The arrays will be tied together by a common index. The structure looks like this:

Index = 0                      Index = 1                      Index = 2                      Index = 3                      Index = 4

#### Questions Array

Question 1	Question 2	Question 3	Question 4	Question 5
------------	------------	------------	------------	------------

#### Answers Array

Answer 1	Answer 2	Answer 3	Answer 4	Answer 5
----------	----------	----------	----------	----------

#### Values Array

Value 1	Value 2	Value 3	Value 4	Value 5
---------	---------	---------	---------	---------

For example, question 3, the answer to question 3, and the point value for question 3 are all stored at index 2 in the respective arrays.

We can hard code these into three separate arrays. Later we'll see how to read them from a file.

```
import java.util.Scanner;

public class TriviaGame
{
    private String[] questions;
    private String[] answers;
    private int[] values;

    private static int NUMQUESTIONS = 5;

    public TriviaGame()          // Constructor
    {
        questions = new String[NUMQUESTIONS];
        answers = new String[NUMQUESTIONS];
        values = new int[NUMQUESTIONS];

        // Manually copy in questions, answers, and values
        questions[0] = "The first Pokemon that Ash receives from" +
            " Professor Oak";
        answers[0] = "pikachu";
        values[0] = 1;
        questions[1] = "Erling Kagge skied into here alone on" +
            " January 7, 1993";
        answers[1] = "south pole";
        values[1] = 2;
        questions[2] = "1997 British band that produced 'Tub '" +
            " Thumper'";
        answers[2] = "chumbawumba";
        values[2] = 2;
        questions[3] = "Who is the tallest person on record " +
            "(8 ft. 11 in) that has lived?";
        answers[3] = "Robert Wadlow";
        values[3] = 3;
        questions[4] = "PT Barnum said 'This way to the _____ '" +
            " to attract people to the exit.";
        answers[4] = "egress";
        values[4] = 1;
    }

    public static void main(String[] args)
    {
        TriviaGame game = new TriviaGame();

        // Print some data as a test to check the arrays
        System.out.println(game.questions[1] + " " +
            game.answers[1] + " " + game.values[1]);
        System.out.println(game.questions[4] + " " +
            game.answers[4] + " " + game.values[4]);
    }
}
```

For a real game we would probably have a lot more questions!

The game will simply ask all questions, outputs if the player is correct or not, and then output the total score. To keep track of these we can add some new variables at the class level:

```
private int score = 0;           // Overall score
private int questionNum = 0;    // Track if question 0 - 4
```

score is an integer that tracks our score. questionNum keeps track of which question we are asking, and will start at 0 and go up to 4, the last question.

To modularize our program a bit, we will need to show a question and to check if an answer is correct, so let's make a method for doing this. Our method will return false if there are no more questions to ask, and true otherwise:

```
// Returns false if there are no more questions to ask.
// Otherwise it asks the next question, gets an answer
// from the user, and displays if the user was correct or not.
public boolean askNextQuestion()
{
    if (questionNum >= questions.length)
    {
        return false;
    }
    // Show the current question
    System.out.println();
    System.out.println("Question " + questionNum);
    System.out.println(questions[questionNum]);
    Scanner kbd = new Scanner(System.in);
    String guess = kbd.nextLine();

    // Check if the answer is correct or not
    guess = guess.toLowerCase();
    if (guess.equals(answers[questionNum].toLowerCase()))
    {
        System.out.println("That is correct!");
        score += values[questionNum];
    }
    else
    {
        System.out.println("Wrong. The correct answer is "
            + answers[questionNum]);
    }

    // Go to next question
    questionNum++;
    return true;
}

// Displays current score
public void showScore()
{
    System.out.println("Your score is " + score);
}
```

Finally here is a main method that loops as long as there is a next question to ask:

```
public static void main(String[] args)
{
    TriviaGame game = new TriviaGame();

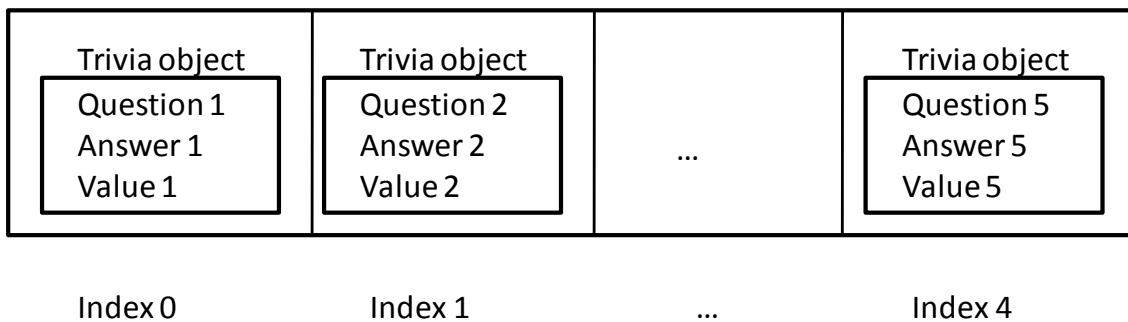
    while (game.askNextQuestion())
    {
        game.showScore();
    }
    System.out.println("Game over! Thanks for playing!");
}
```

## Trivia Game with Classes

As an example of arrays with classes, we can modify our program to use a single array of a class instead of three separate arrays. The approach with separate arrays is not really scalable if we had more properties associated with each question. For example, if we also wanted to associate an author, date added, and alternate answer, then we would have to add three more arrays. This quickly becomes untenable for a large number of properties. Additionally, if the arrays ever get out of sync (e.g. the answer to question 3 somehow ends up in index 4 instead of index 2) then great havoc will ensue.

A better approach is to make a single object that stores all of the data of interest regarding a trivia question, then make one array of those objects. A diagram is shown below:

Trivia Array



First let's make a Trivia class that encapsulates information about one trivia question:

```
public class Trivia
{
    private String question;
    private String answer;
    private int value;

    // Constructor to set the question, answer, and value
    public Trivia(String question, String answer, int value)
    {
        this.question = question;
        this.answer = answer;
        this.value = value;
    }

    // Accessor methods to retrieve the question, answer, value
    public String getQuestion()
    {
        return question;
    }

    public String getAnswer()
    {
        return answer;
    }
}
```

```

    public int getValue()
    {
        return value;
    }
}

```

Now we can modify our TriviaGame class to use the Trivia class instead. We eliminate the three arrays of questions, answers, and values and replace it with a single array called trivia:

```
private Trivia[] trivia;
```

Our constructor now looks like this to set up all the questions, answers, and values:

```

public TriviaGame()           // Constructor
{
    trivia = new Trivia[NUMQUESTIONS];

    // Manually copy in questions, answers, and values
    // Note that we need to use NEW to create the instance of each
    // object to store in the array

    trivia[0] = new Trivia("The first Pokemon that Ash receives from
Professor Oak", "pikachu",1);

    trivia[1] = new Trivia("Erling Kagge skied into here alone on
January 7, 1993", "south pole", 2);

    trivia[2] = new Trivia("1997 British band that produced 'Tub
Thumper'", "chumbawumba", 2);

    trivia[3] = new Trivia("Who is the tallest person on record (8
ft. 11 in) that has lived?","Robert Wadlow", 3);

    trivia[4] = new Trivia("PT Barnum said 'This way to the _____'
to attract people to the exit.", "egress", 1);
}

```

Note that we use the keyword **new** twice. Once to create the array and then again for each object we place in the array. The creation of the array does not create all the objects that will be stored in the array, that requires another invocation of new.

Here is the rest of the program which is modified to use the trivia array. The only changes needed are in the askNextQuestion method, which must use:

```
trivia[index].getProperty()
```

in place of:

```
property[index]
```

```

// Returns false if there are no more questions to ask.
// Otherwise it asks the next question, gets an answer
// from the user, and displays if the user was correct or not.
public boolean askNextQuestion()
{
    if (questionNum >= trivia.length)
    {
        return false;
    }
    // Show the current question
    System.out.println();
    System.out.println("Question " + questionNum);
    System.out.println(trivia[questionNum].getQuestion());
    Scanner kbd = new Scanner(System.in);
    String guess = kbd.nextLine();

    // Check if the answer is correct or not
    guess = guess.toLowerCase();
    String answer =
trivia[questionNum].getAnswer().toLowerCase();
    if (guess.equals(answer))
    {
        System.out.println("That is correct!");
        score += trivia[questionNum].getValue();
    }
    else
    {
        System.out.println("Wrong. The correct answer is "
            + trivia[questionNum].getAnswer());
    }

    // Go to next question
    questionNum++;
    return true;
}

```

Later we will see how to read the trivia questions in from a file, which will make this program much more flexible and expandable.