CS18000: Problem Solving and Object-Oriented Programming

Arrays
Video 1
Introduction to Arrays
Arrays

Concepts
Syntax
Examples
Lots of Temperatures

Three temperatures:
double tempAM, tempNoon, tempPM;

24 temperatures:
double temp1AM, temp2AM, ... tempNoon, temp1PM, ... tempMidnight;

Mathematicians have solved this problem
Subscripted variables
temp_1, temp_2, ... temp_24

Java uses
double[] temp = new double [24];
which creates temp[0], temp[1], ..., temp[23]
Lots of Temperatures

<table>
<thead>
<tr>
<th>length</th>
<th>temp</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Our Next Advance

• Single variables holding single values is not enough

• Need...
  – Ways to deal with data in bulk
  – Treat a collection of values as single unit

• Also known as “data structures” and “aggregate data types”

• Arrays are just one example
Data Structure Characteristics

• Contents: types of the values
  – heterogeneous data values, or
  – homogeneous data values

• Size: number of data values it contains
  – static (fixed size)
  – dynamic (can grow or shrink)

• Element access: how efficiently can different elements be inserted, deleted, or changed?
  – Sequential access
  – Random access
Arrays

• An array is a list of values
• A kind of “container object” in Java
• In Java, arrays are
  – homogeneous
  – static
  – random access
  – reference types
• Analogy: a String is like an array of characters
Video 2
Using Arrays
A Familiar Example

```java
public static void main(String[] args) {
    // The parameter to main is an array of Strings
    // Array args initialized from the space-separated “words” on the command line
    String[] args = new String[3];
    args[0]: first argument
    args[1]: second argument
    args[i]: i\text{th} argument
    args.length == number of arguments
```
A Familiar Example

```plaintext
args

length 3

0

1

2

"add"

"5"

"17.25"
```
An Example of the Familiar

```java
public class Calculate {
    public static void main(String[] args) {
        for (int i = 0; i < args.length; i++)
            System.out.printf(
                "args[%d] = %s\n", i, args[i]);
    }
}
```
Declaring an Array Variable

• Example:
  String[] args

• In general:
  \textit{type\_name} [ ] \textit{variable\_name}

• \textit{type\_name}: any primitive or reference type

• \textit{variable\_name}: a standard Java identifier
Creating an Array Object

• Example:
  
  `new String[10]`

• In general:
  
  `new type_name[size]`

• `type_name`: any primitive or reference type
• `size`: an int-valued expression
• `String[]` `students = new String[10];`
  
  or

• `var students = new String[10];`
Accessing an Array Element

• Example:
  \texttt{args[0]} or \texttt{args[i]}

• In general:
  \texttt{array\_object\_reference [ int\_value ]}

• \texttt{array\_object\_reference}: an expression (e.g., variable) that references an array object

• \texttt{int\_value}: an expression that yields an int
int[] list = new int[5];

declare list

assign

create

list[3]

reference
Video 3
WordList Array Example
Problem: WordList

• Create a WordList class that reads words from a file into an array
• Create a computeHistogram method in WordList that computes the number of words of each length in the WordList
• Need to
  – Declare array variables for the main word list and to hold the histogram counts
  – Choose suitable maximum lengths and allocate
Step 1: WordList

- Create WordList class
- What information (fields) should be stored in a WordList object?
  - words: an array containing the words
  - size: the number of actual words in the array
- How should the object be initialized?
  - Constructor takes a Scanner object
  - Allocates “big” array
  - Reads words from Scanner and stores in array
Step 2: WordList

• Create a main method for testing
• Create a Scanner object with String of words
• Create a WordList object
• Print
  – Number of words found
  – List of words
Step 3: Create Histogram

• Add method “int[] computeHistogram()”
• Allocate an array of ints to store the histogram
• How big? Pick a number
• Loop through all the words in the list
  – Get the length of the word
  – Update the histogram counter of that length
• Return the histogram array
• In main: call, then print results
import java.util.Scanner;

public class WordList {
    final static int MAXWORDS = 300000;   // Problem we will discuss later!
    final static int MAXHIST = 50;

    private String[] words;
    private int size;

    public WordList(Scanner in) {
        words = new String[MAXWORDS];
        size = 0;

        while (in.hasNext()) {
            words[size++] = in.next();
        }
    }
}
Solution: WordList (2)

```java
public int getSize() {
    return size;
}

public int[] computeHistogram() {
    var histogram = new int[MAXHIST];

    for (int i = 0; i < size; i++)
        histogram[words[i].length()]++;

    return histogram;
}
```
public static void main(String[] args) {
    Scanner scan = new Scanner(System.in);
    WordList w = new WordList(scan);
    System.out.printf("read %d words\n", w.getSize());

    int[] wordLengths = w.computeHistogram();
    for (int i = 1; i < MAXHIST; i++)
        if (wordLengths[i] > 0)
            System.out.printf("%2d: %5d\n", i, wordLengths[i]);
}

Solution: WordList

<table>
<thead>
<tr>
<th>length</th>
<th>300000</th>
</tr>
</thead>
<tbody>
<tr>
<td>words</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>null</td>
</tr>
<tr>
<td></td>
<td>null</td>
</tr>
<tr>
<td></td>
<td>null</td>
</tr>
<tr>
<td></td>
<td>6999</td>
</tr>
<tr>
<td></td>
<td>299999</td>
</tr>
</tbody>
</table>

| size   | 0      |
Solution: WordList

<table>
<thead>
<tr>
<th>wordLengths</th>
<th>3</th>
<th>7</th>
<th>49</th>
</tr>
</thead>
<tbody>
<tr>
<td>histogram</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>length</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Video 4
TreeTracker Array Example
Array Initialization

• Default: elements initialized with type-specific default
  – Integer types: 0
  – Real types: 0.0
  – Reference types: null

• Compile-time array initialization possible

• Example:
  
  ```
  char[] vowels = { 'a', 'e', 'i', 'o', 'u' };
  ```

• In general:

  ```
  array_declaration = { v_1, v_2, ... v_n };
  ```

  ```
  int[] days = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31};
  ```

• Note: Initialization must be done in conjunction with (at time of) declaration
Problem: TreeTracker

• The National Forest Service needs our help...
• Create a TreeTracker class that creates random Tree objects (for testing)
  – Generate random species and circumferences
  – Store them in an array and print out using the describe method
• Illustrates: array initialization, pseudo-random numbers, length field in arrays
public class Tree {
    private int serial;
    private double circumference;
    private String species;

    public Tree(int serial, double circumference, String species) {
        this.serial = serial;
        this.circumference = circumference;
        this.species = species;
    }

    public String describe() {
        return String.format("Tree number %d has a circumference of %.2f and is of species %s.", serial, circumference, species);
    }

    public double getDiameter() {
        return circumference / Math.PI;
    }

    public double getCircumference() {
        return circumference;
    }
}
Random Class

A Random Class object can be used to generate a random number

You must...
import java.util.Random;
...and declare a Random object...
Random r = new Random();

r.nextDouble() returns a value in the range [0.0-1.0) (same as Math.random())
r.nextInt(int n) returns a value in the range [0-n)
r.nextInt() returns any possible integer positive or negative number
import java.util.Random;

public class TreeTracker {
    final static int NUMTREES = 100;

    public static void main(String[] args) {
        Random r = new Random();
        String[] species = { "pine", "elm", "spruce", "oak", "walnut" };

        var trees = new Tree[NUMTREES];

        for (int i = 0; i < trees.length; i++) {
            String specie = species[r.nextInt(species.length)];
            trees[i] = new Tree(i, r.nextDouble()*100, specie);
        }

        for (int i = 0; i < trees.length; i++)
            System.out.println(trees[i].describe());
    }
}
Solution: TreeTracker

```
<table>
<thead>
<tr>
<th>length</th>
<th>species</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
```

- species 0: "pine"
- species 1: "elm"
- species 2: "spruce"
- species 3: "oak"
- species 4: "walnut"
Solution: TreeTracker
Video 1
Two-dimensional arrays, for-each loops, varargs
Array Elements Can Be Other Arrays!

```java
int[][] matrix = new int[5][10];
```

- Creates a 2D matrix with 5 rows and 10 columns
  ```java
  {{ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 },
  { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 },
  { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 },
  { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 },
  { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 }}
  ```
- Elements of matrix[i] are arrays of (10) ints.
A Java 5x10 Matrix

matrix[i][j]

matrix.length is 5
matrix[i].length is 10 (for all i in this example)
Uses of 2D Arrays

• Representing
  – A grid-based game, like tic-tac-toe or chess
  – A set of distances between pairs of cities
  – Matrices in linear algebra
  – Other tabular data

• Generalizable to additional dimensions
  
  ```java
  double[][][][] spaceTime = new double[100][100][100][100];
  ```

• Note: Above requires 100,000,000 storage locations
Quirks

• There is no requirement in Java that all rows of a 2-D matrix have the same number of elements ("columns")
• Allows “ragged right" arrays (aka “jagged right”)
• Useful for saving storage
Declaring a Ragged Array

int[][] matrix = new int [5][];

matrix[0] = new int [7];
matrix[1] = new int [10];
matrix[2] = new int [4];
matrix[3] = new int [6];
matrix[4] = new int [9];
Problem: Sum Matrix

Compute the sum of a 2D array...

```java
int computeSum() {
    int sum = 0;
    for (int i = 0; i < matrix.length; i++)
        for (int j = 0; j < matrix[i].length; j++)
            sum += matrix[i][j];
    return sum;
}
```

Note: This solution works even for ragged arrays.
The for-each Loop

- Designed for use with arrays (and, more importantly, other data structures to come)
- Allows simplified iteration through an array
  ```java
  int[] bloodPressure = new int [500];
  int sum = 0;
  for (i=0; i<bloodPressure.length; i++)
      sum += bloodPressure[i];
  for (int value : bloodPressure)
      sum += value;
  ```
- Limitation: only read-access to each element
varargs

• varargs is short for variable-length arguments
• method that takes a variable number of arguments is a varargs method
• A variable-length argument is specified by three periods(...)  
  
  public static void func (int ... a)  
  {  
      // method body  
  }
• tells the compiler that func() can be called with zero or more arguments
• a is implicitly declared as an array of type int[]
varargs

public static void main (String[] args) {
    func (100);         // sends array {100}
    func (1, 2, 3, 4);  // sends array {1,2,3,4}
    func ();            // sends array {}
}

• varargs has been used and these arguments should be stored in the int array referred to by a
• a.length can be used to find the length of the array
• A method can have variable length parameters with other parameters too, but the varargs parameter should be last in the parameter list of the method declaration

    int nums (int a, float b, double ... c)
Video 2
ArrayLists
Generic Classes

• An advanced topic to be covered more fully later
• Basic idea: A generic class is one that can be parameterized with another class
• ArrayList<E> is parameterized with class (or type) E. It can only “hold” elements that are references to objects of class E
• E must be a reference type; primitive types are not supported
ArrayList Class

• A class provided in the java.util package
• Dynamic array: automatically grows to accommodate new items
• Works with any type of object, but you must specify the type when the ArrayList object is created (just like a Java array)
• Example
  ```java
  ArrayList<String> list = new ArrayList<String>();
  Creates an empty array of String objects
  String[] list = new String[10];
  ```
ArrayList Class

ArrayList<String> list = new ArrayList<String>();

is correct and complete, but we can use Local Variable Type Inference

var list = new ArrayList<String>();

or the second argument can be inferred

ArrayList<String> list = new ArrayList<>();
ArrayList Class

• Unlike Java arrays, ArrayList does not work with primitive types, only reference types
• Can’t say “ArrayList<int> list”
• Fortunately, Java provides special “wrapper” classes for each primitive type
• Can say “ArrayList<Integer> list”
• Java handles the conversion between wrapper class and corresponding primitive type
Useful ArrayList Methods

- `add(e)` – adds e to end of list
- `add(i, e)` – adds e at index i (0-based), pushing others down
- `contains(e)` – returns true if e is in the list
- `get(i)` – returns the value at index i
- `remove(e)` – removes e from the list
- `set(i, e)` – adds e at index i, replacing what was there
- `size()` – returns the current size of the list
Useful ArrayList Methods

```java
ArrayList<String> list = new ArrayList<String>();

list.add("A");
list.add("B");
list.add("C");
list.add(1, "D");
list.get(2);
list.set(1, "E");
```
When Should You Use an ArrayList?

You CAN use an ArrayList any time in place of an array. ArrayLists can do everything an array can ... and more.

You SHOULD use an ArrayList

• When you have no idea how many items will be in the array
• When you want to take advantage of add(i,e) which adds e at index i and pushes everything else down
import java.util.Scanner;

public class WordList {
    final static int MAXHIST = 50;

    private ArrayList<String> words = new ArrayList<String>();

    public WordList(Scanner in) {
        while (in.hasNext()) {
            words.add(in.next());
        }
    }
}
public int getSize() {
    return words.size();
}

public int[] computeHistogram() {
    var histogram = new int[MAXHIST];
    for (int i = 0; i < words.size(); i++)
        histogram[words.get(i).length()]++;
    return histogram;
}
import java.util.ArrayList;
import java.util.Scanner;

public class ArrayListDemo {
    public static void main(String[] args) {
        var list = new ArrayList<String>();

        Scanner in = new Scanner(System.in);

        while (in.hasNextLine()) {
            String s = in.nextLine();
            list.add(s);
        }

        System.out.printf("read %d lines\n", list.size());

        for (int i = 0; i < list.size(); i++) {
            System.out.printf("%s\n", list.get(i));
        }
    }
}
TreeList Class

```java
import java.util.ArrayList;

public class TreeList {
    public static void main(String[] args) {
        var forest = new ArrayList<Tree>();

        while (Math.random() < 0.9) {
            Tree t = new Tree(Math.random() * 100);
            System.out.printf("tree has radius %.3f\n", t.getRadius());
            forest.add(t);
        }

        System.out.printf("created %d trees\n", Tree.getNumberOfTrees());

        System.out.printf("list has %d trees:\n", forest.size());
        for (Tree t : forest)
            System.out.printf("tree with radius %.3f\n", t.getRadius());
    }
}
```
Arrays Class

• Useful utility methods for dealing with arrays
  import java.util.Arrays;

• Work with arrays of many types (not just int and double)

  Arrays.binarySearch(int[] array, int value)
  Arrays.copyOf(double[] array, int length)
  Arrays.copyOfRange(double[] array, int from, int to)
  Arrays.equals(int[] array1, int[] array2)
  Arrays.fill(double[] array, double value)
  Arrays.sort(int[] array)
  Arrays.toString(double[] array)
Generalizations

• A method can take an array as parameter
  – int computeSum(int[] a)
  – public static void main(String[] args)

• A method can return an array as return value
  – int[] sortIntegers(int[] a)
  – int[] computeHistogram()

• An array of type $T[\ ]$, has elements of type $T$
Video 3
Playing Cards Array Example
Problem: Model Playing Cards

• Create a class that models a deck of playing cards
• Features needed:
  – Draw cards at random from the deck
  – Shuffle
  – Convert card representation to suit and value string
Representing Cards

• Represent suits as ints 0-3
  – H, S, D, C
  – 0, 1, 2, 3

• Represent card values as ints 0-12
  – A, 2, 3, 4, 5, 6, 7, 8, 9, T, J, Q, K
  – 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

• Represent a card in a single int as
  – suit * 13 + value
  – Each card is a value in the range 0-51 (inclusive)
  – suit is (card / 13); value is (card % 13)
Representing Cards

- six of diamonds
- suit = 2
- value = 5
- suit \times 13 + value = 31

- What card is 31?
- suit is \( \text{card} \div 13 \) = 2 (diamonds)
- value is \( \text{card} \mod 13 \) = 5 (six)
Representing a Deck of Cards

- Use an int array with 52 locations
- Locations are (initially) values 0-51
- That is: \( \text{deck}[i] == i \) for all \( i \)
- Thus, deck is initially
  - Sorted by suits then by value
  - All cards are available to be drawn
- To draw a card
  - Choose card at random from available cards
  - Swap chosen card with last card in deck
  - Reduce available cards by 1
- To shuffle
  - Set available cards to 52
Initial Deck Representation

deck

size 52

int[]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>(AH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>(2H)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>(3H)</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>(4H)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>(5H)</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>(6H)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>51</td>
<td>(KC)</td>
</tr>
</tbody>
</table>
Drawing a Card at Random

Deck:

size = 52

r.nextInt(size) -> 5

Swap card 5 (6H) and 51 (KC)

Decrement size by 1
Drawing a Card at Random

int[]

0  0  (AH)
1  1  (2H)
2  2  (3H)
3  3  (4H)
4  4  (5H)
5  51 (KC)

r.nextInt(size) -> 5
Swap card 5 (6H) and 51 (KC)
Decrement size by 1
Solution: DeckOfCards