AP Computer Science A

Java Programming Essentials [Ver.4.0]

Unit 4: Data Collections

CHAPTER 18: 2D ARRAY PROCESSING

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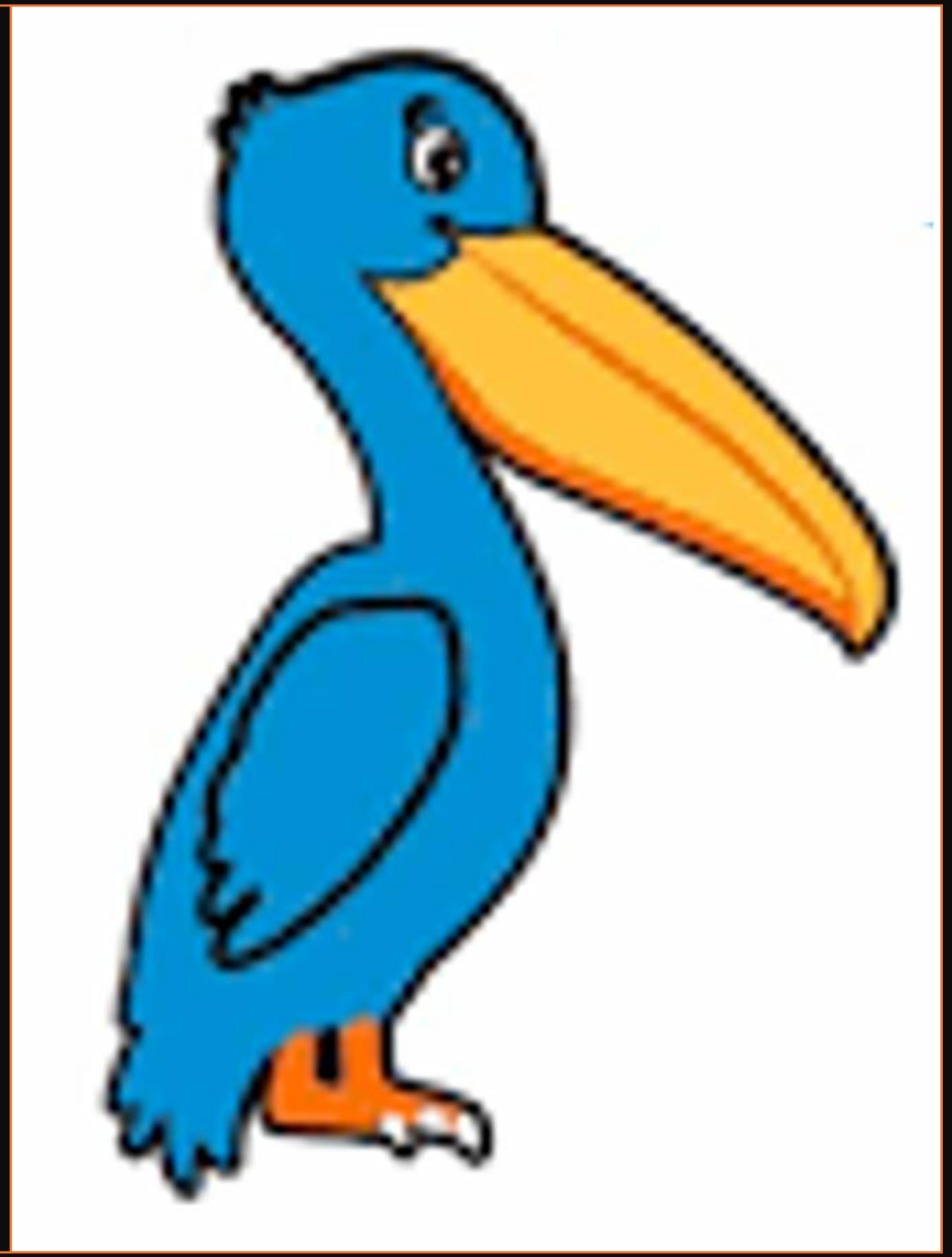


AP Computer Science Curriculum

- Implementing 2D Array Algorithms (T4.13)

Objectives:

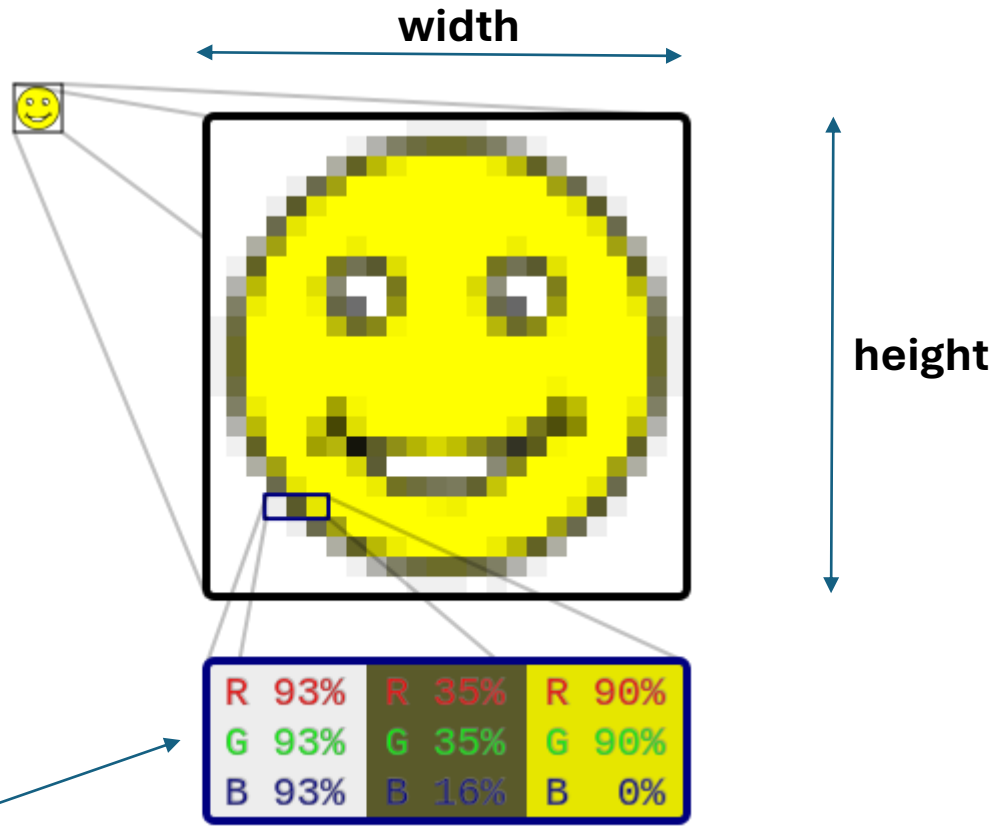
- Image Processing
- Symmetric 2D Array: k-graph, closest points
- Combination Number: Binomial Theorem
- N-D Arrays

2-D Array Image Processing

Lecture 1

An Raster-based Image is an 2-D Array of Pixels with Color

https://en.wikipedia.org/wiki/Raster_graphics



3D-Color vector (by percentage, or by strength (0-255), if alpha channel (opacity) is also included.

java.awt.Color

- The class java.awt.Color provides 13 standard colors as named-constants. They are: Color.RED, GREEN, BLUE, MAGENTA, CYAN, YELLOW, BLACK, WHITE, GRAY, DARK_GRAY, LIGHT_GRAY, ORANGE, and PINK. (In JDK 1.1, these constant names are in lowercase, e.g., red. This violates the Java naming convention for constants. In JDK 1.2, the uppercase names are added. The lowercase names were not removed for backward compatibility.)
- You can use the toString() to print the RGB values of these color (e.g., System.out.println(Color.RED)):

Color Vector (4D, Red/Green/Blue/Alpha)

(Alpha channel is not shown here.)

```
RED          : java.awt.Color[r=255, g=0,   b=0]
GREEN        : java.awt.Color[r=0,   g=255, b=0]
BLUE         : java.awt.Color[r=0,   g=0,   b=255]
YELLOW       : java.awt.Color[r=255, g=255, b=0]
MAGENTA      : java.awt.Color[r=255, g=0,   b=255]
CYAN         : java.awt.Color[r=0,   g=255, b=255]
WHITE        : java.awt.Color[r=255, g=255, b=255]
BLACK        : java.awt.Color[r=0,   g=0,   b=0]
GRAY         : java.awt.Color[r=128, g=128, b=128]
LIGHT_GRAY   : java.awt.Color[r=192, g=192, b=192]
DARK_GRAY    : java.awt.Color[r=64,  g=64,  b=64]
PINK         : java.awt.Color[r=255, g=175, b=175]
ORANGE       : java.awt.Color[r=255, g=200, b=0]
```

Gray Level Image

(R=G=B, all three channels have the same strength)

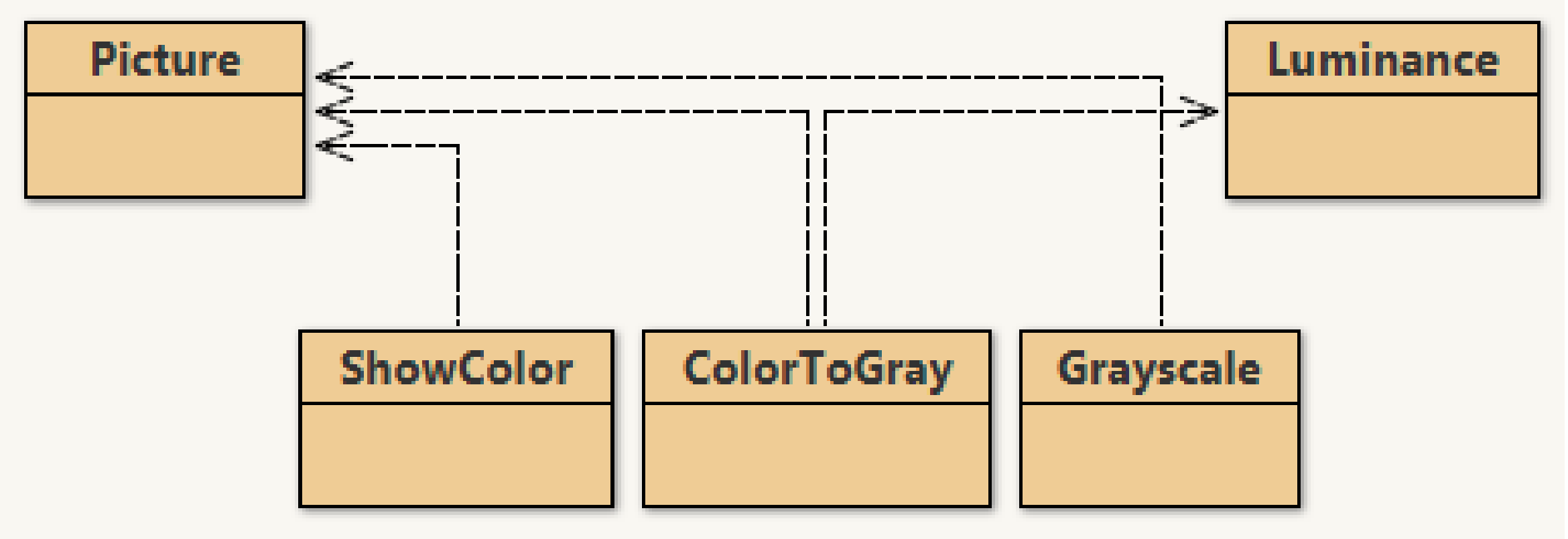
- A **grayscale** (or graylevel) image is simply one in which the only colors are shades of gray. The reason for differentiating such images from any other sort of color image is that less information needs to be provided for each pixel. In fact a `gray' color is one in which the red, green and blue components all have **equal intensity** in **RGB space**, and so it is only necessary to specify a single intensity value for each pixel, as opposed to the three intensities needed to specify each pixel in a full color image.

- Often, the grayscale intensity is stored as an **8-bit** integer giving **256** possible different shades of gray from black to white. If the levels are evenly spaced then the difference between successive graylevels is significantly better than the graylevel resolving power of the human eye.

Demo Program: Graylevel.zip

(include Picture.java Luminance.java, ShowColor.java, ColorToGray.java, Graylevel.java)

- **Picture.java:** handling basic image functions. Do not worry about it right now.
- **Luminance.java:** convert a color into a gray level color (still color but with same intensity for all three RGB channels.)
- **ShowColor.java:** show a color image potentialColor.png
- **ColorToGray.java:** convert the color image to gray level image.
- **Graylevel.java:** our program of interests.
- adjust the brightness level of an image by increase the brightness level
- or darken it by adding a negative brightness level.
- The potentialColor.png and potentialGray.png both are images size of 250 by 250 pixels.


Picture
Luminance
ShowColor
ColorToGray
Grayscale

Demonstration Program

Picture.java +Luminance.java

ShowColor.java

ColorToGray.java

GrayScale.java

Passing 2D Arrays to Methods

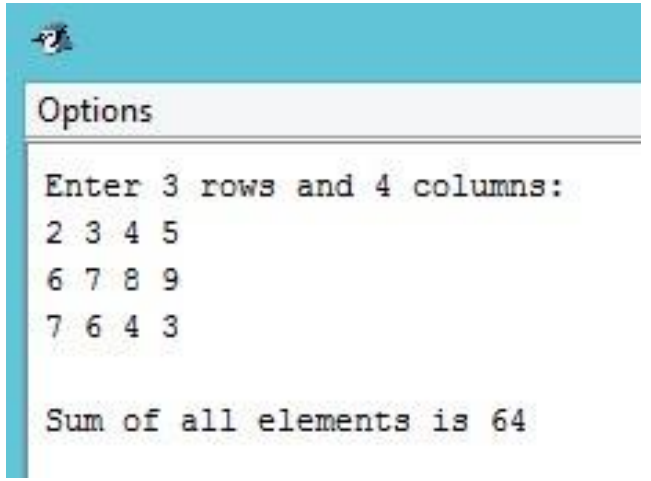
Lecture 2

Passing Two-Dimensional Arrays to Methods

- You pass a two-dimensional array to a method just as you pass a one-dimensional array. You also return an array from a method. **Pass2DArray.java** program gives an example with two methods. The first method, getArray(), returns a two-dimensional array, and the second method, sum(int[][] m), returns the sum of all elements in a matrix.
- ***Go BlueJ …***

Passing Two-Dimensional Arrays to Methods

- The method getArray prompts the user to enter values for the array (lines 11-24) and returns the array (line 23).
- The method sum (lines 26-35) has a two-dimensional array argument. You can obtain the number of rows using m.length (line 28) and the number of columns in a specified row using m[row].length (line 29).



Demonstration Program

Pass2DArray.java

Application Grading Multiple-Choice Tests

Lecture 3

Problem: Grading Multiple-Choice Test

StudentAnswer.java (Grading for a class on a subject)

Students' Answers to the Questions:

	0	1	2	3	4	5	6	7	8	9
Student 0	A	B	A	C	C	D	E	E	A	D
Student 1	D	B	A	B	C	A	E	E	A	D
Student 2	E	D	D	A	C	B	E	E	A	D
Student 3	C	B	A	E	D	C	E	E	A	D
Student 4	A	B	D	C	C	D	E	E	A	D
Student 5	B	B	E	C	C	D	E	E	A	D
Student 6	B	B	A	C	C	D	E	E	A	D
Student 7	E	B	E	C	C	D	E	E	A	D

- Objective: write a program that grades multiple-choice test.

Key to the Questions:

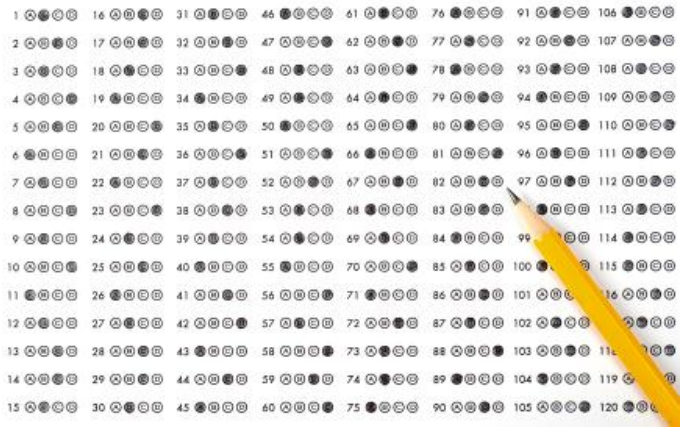
	0	1	2	3	4	5	6	7	8	9
Key	D	B	D	C	C	D	A	E	A	D

Demonstration Program

StudentAnswer.java

Ragged Array for Student's Score for Multiple Subjects

StudentScoreMultiple.java



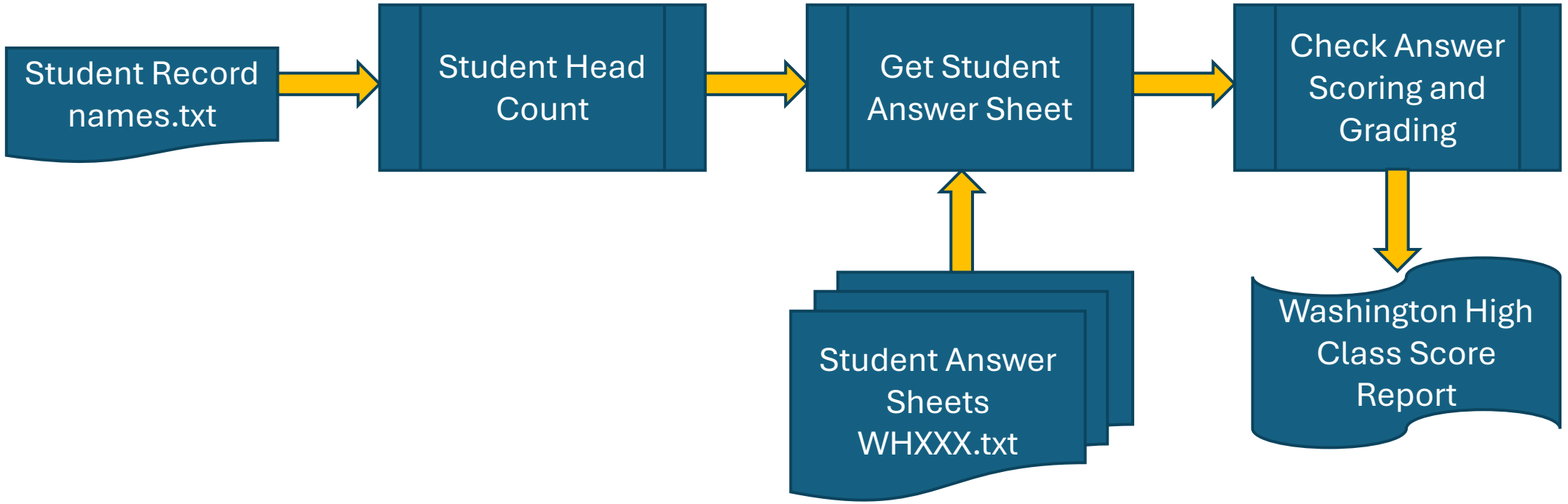
Student Answer Sheet

Answer Sheet Scanning Reader

Student Answer Sheet Text File
WH000.txt

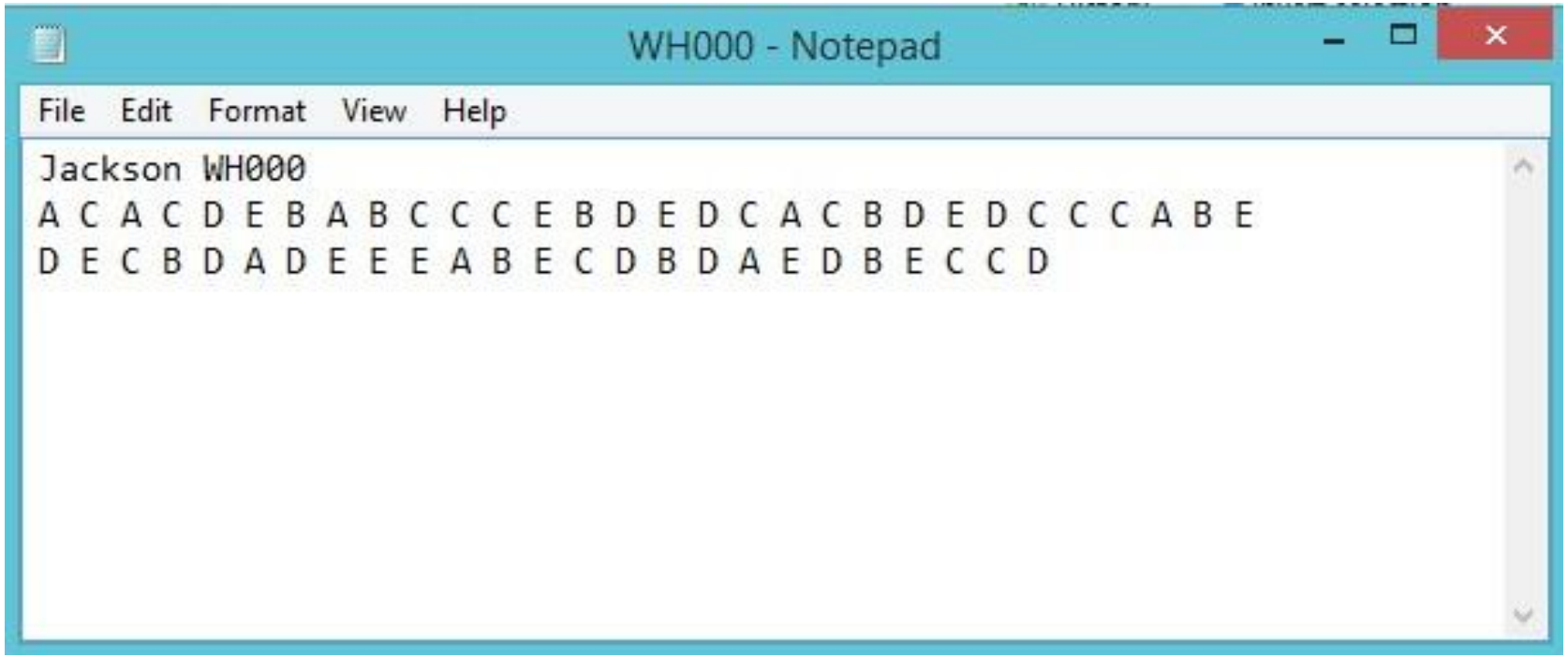
Data Flow Diagram

StudentScoreMultiple.java



Student Record and Answer Sheet

Student Record names.txt



Answer Sheet WH000.txt

Data Structure for Student Records

```
// declaration of the data structures for the class
String[] names    = new String[lines];
int[] mathScore   = new int[lines];
int[] engScore    = new int[lines];
char[] mathGrade = new char[lines];
char[] engGrade   = new char[lines];
// new data
String[] studentID = new String[lines];              // student ID
char[]   mathAnswer = new char[MATH_QUESTION_NUM]; // math answer row
char[]   engAnswer  = new char[ENG_QUESTION_NUM];  // english answer row
char[][] answerSheet = { mathAnswer, engAnswer };  // ragged array for the answer sheet for math and english
```

```
// setup for answer keys
final static int MATH_QUESTION_NUM = 30;
final static int ENG_QUESTION_NUM = 25;
```

```
final static char[] mathKey = {A, B, A, C, D, E, E, A, B, C,
                               C, C, E, B, D, D, D, C, A, C,
                               B, D, E, A, C, C, C, A, B, E};

final static char[] engKey = {D, E, C, B, D, A, C, E, E, E,
                              A, B, E, C, D, B, D, A, A, D,
                              B, E, A, C, D};
```

Random Answer Sheet

(for program testing purpose)

```
public static char randomAnswer(){
    int i = (int) (Math.random()*5);
    if (i==0)      return A;
    else if (i==1) return B;
    else if (i==2) return C;
    else if (i==3) return D;
    else           return E;
}
```

```
public static void createAnswerSheet(File oFile, String names, String studentID) throws IOException {
    PrintWriter out = new PrintWriter(oFile);
    out.println(names+" "+studentID);
    double bias = Math.random()*0.5 + 0.4; // random bias value ranging from 0.4 to 0.9
    for (int i=0; i<MATH_QUESTION_NUM; i++){
        if (Math.random()<bias) out.print(mathKey[i]+" "); else out.print(randomAnswer()+" ");
       }
    out.println();
    bias = Math.random()*0.5 + 0.42;  // random bias vaue ranging from 0.42 to 0.92
    for (int i=0; i<ENG_QUESTION_NUM; i++){
        if (Math.random()<bias) out.print(engKey[i]+" "); else out.print(randomAnswer()+" ");
       }
    out.close();
}
```

resetAnswerSheet() and checkAnswerSheet)

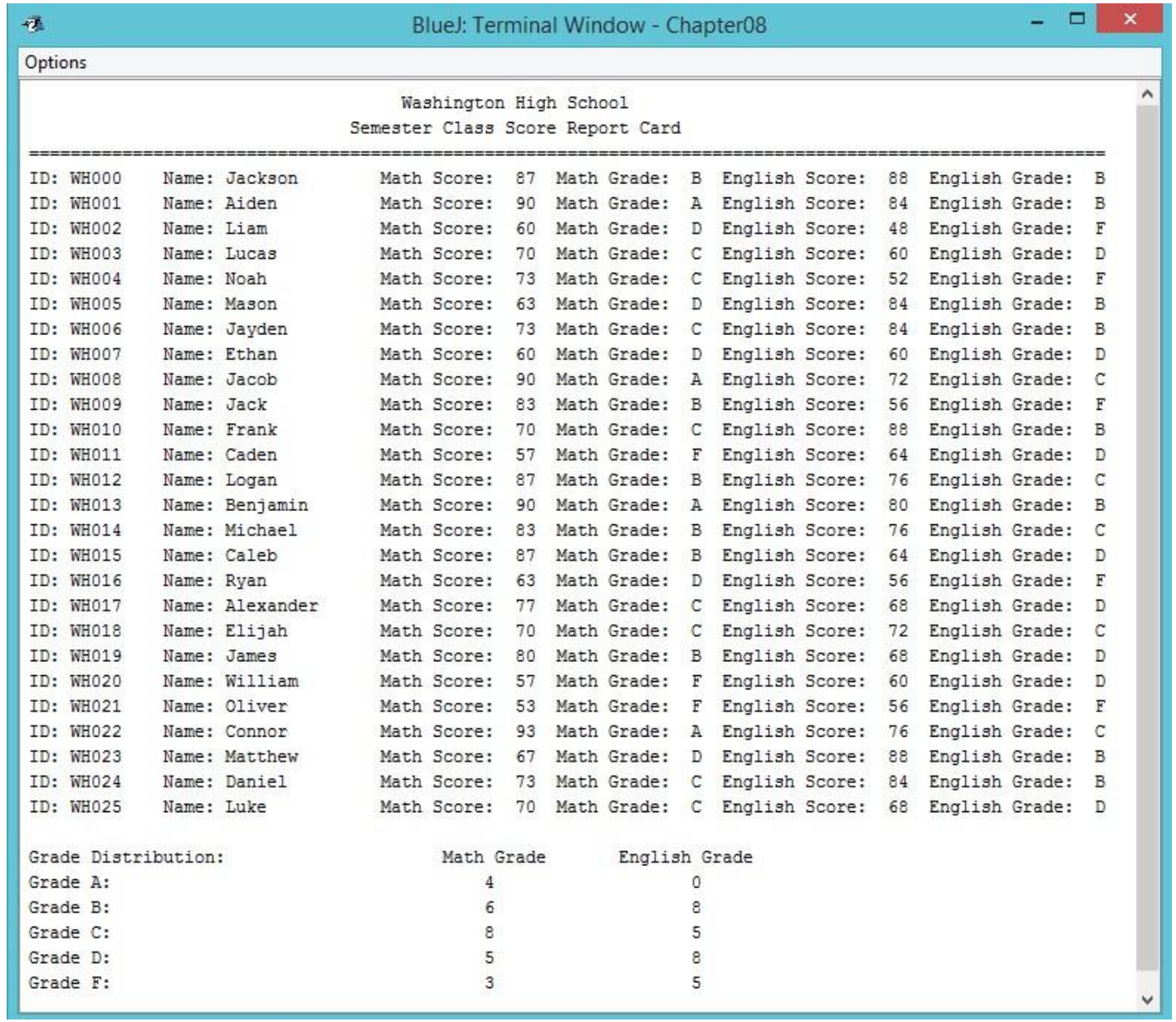
Invoking checkAnswer()

```
mathScore[i] = checkAnswer(mathKey, answerSheet[0]);
engScore[i]  = checkAnswer(engKey,  answerSheet[1]);
```

```
public static void resetAnswerSheet(char[][] answerSheet){
  for (int j=0; j<MATH_QUESTION_NUM; j++) answerSheet[0][j] = S;
  for (int j=0; j<ENG_QUESTION_NUM;  j++) answerSheet[1][j] = S;
}
```

```
public static int checkAnswer(char[] key, char[] answer){
    double sum = 0;
    //System.out.println(key.toString);
    for (int i=0; i<key.length; i++){
      if (key[i] == answer[i]) sum += 1.0;
    }

    int score = (int) Math.round(sum/key.length*100);
    return score;
}
```


BlueJ: Terminal Window - Chapter08
Options
Washington High School
Semester Class Score Report Card
ID: WH000 Name: Jackson Math Score: 87 Math Grade: B English Score: 88 English Grade: B
ID: WH001 Name: Aiden Math Score: 90 Math Grade: A English Score: 84 English Grade: B
ID: WH002 Name: Liam Math Score: 60 Math Grade: D English Score: 48 English Grade: F
ID: WH003 Name: Lucas Math Score: 70 Math Grade: C English Score: 60 English Grade: D
ID: WH004 Name: Noah Math Score: 73 Math Grade: C English Score: 52 English Grade: F
ID: WH005 Name: Mason Math Score: 63 Math Grade: D English Score: 84 English Grade: B
ID: WH006 Name: Jayden Math Score: 73 Math Grade: C English Score: 84 English Grade: B
ID: WH007 Name: Ethan Math Score: 60 Math Grade: D English Score: 60 English Grade: D
ID: WH008 Name: Jacob Math Score: 90 Math Grade: A English Score: 72 English Grade: C
ID: WH009 Name: Jack Math Score: 83 Math Grade: B English Score: 56 English Grade: F
ID: WH010 Name: Frank Math Score: 70 Math Grade: C English Score: 88 English Grade: B
ID: WH011 Name: Caden Math Score: 57 Math Grade: F English Score: 64 English Grade: D
ID: WH012 Name: Logan Math Score: 87 Math Grade: B English Score: 76 English Grade: C
ID: WH013 Name: Benjamin Math Score: 90 Math Grade: A English Score: 80 English Grade: B
ID: WH014 Name: Michael Math Score: 83 Math Grade: B English Score: 76 English Grade: C
ID: WH015 Name: Caleb Math Score: 87 Math Grade: B English Score: 64 English Grade: D
ID: WH016 Name: Ryan Math Score: 63 Math Grade: D English Score: 56 English Grade: F
ID: WH017 Name: Alexander Math Score: 77 Math Grade: C English Score: 68 English Grade: D
ID: WH018 Name: Elijah Math Score: 70 Math Grade: C English Score: 72 English Grade: C
ID: WH019 Name: James Math Score: 80 Math Grade: B English Score: 68 English Grade: D
ID: WH020 Name: William Math Score: 57 Math Grade: F English Score: 60 English Grade: D
ID: WH021 Name: Oliver Math Score: 53 Math Grade: F English Score: 56 English Grade: F
ID: WH022 Name: Connor Math Score: 93 Math Grade: A English Score: 76 English Grade: C
ID: WH023 Name: Matthew Math Score: 67 Math Grade: D English Score: 88 English Grade: B
ID: WH024 Name: Daniel Math Score: 73 Math Grade: C English Score: 84 English Grade: B
ID: WH025 Name: Luke Math Score: 70 Math Grade: C English Score: 68 English Grade: D
Grade Distribution: Math Grade English Grade
Grade A: 4 0
Grade B: 6 8
Grade C: 8 5
Grade D: 5 8
Grade F: 3 5

Demonstration Program

StudentScoreMultiple.java

Demo Program:

Finding the Closest Pair of Points

Lecture 4

Problem: Finding Two Points Nearest to Each Other (FindingClosestPair.java)

```
double[][] points = { {  -1, 0, 3}, { -1, -1 ,  -1},
                      {   4, 1, 1}, {  2,0.5,   9},
                      { 3.5, 2,-1}, {  3, 1.5,   3},
                      {-1.5, 4, 2}, {5.5,  4,-0,5}
                    };
```

- 3-D points in 2-D array. Each row is a 3-tuple 3-D points.

Distance of 2 3D points

- Row array points[i] is actually a point of 3 tuple. points[0]= { -1, 0, 3};

which represents a point (x, y, z) in 3D space.

- So, the distance of Two 3D points can be calculated by:

```
distance=Math.pow((p1[0]-p2[0])*(p1[0]-p2[0])
                  +(p1[1]-p2[1])*(p1[1]-p2[1])
                  +(p1[2]-p2[2])*(p1[2]-p2[2]), 0.5);
```

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

8 points has totally 28 line segments to compare for the closest pair.

	p[1]	p[2]	p[3]	p[4]	p[5]	p[6]	p[7]
p[0]	d	d	d	d	d	d	d
p[1]		d	d	d	d	d	d
p[2]			d	d	d	d	d
p[3]				d	d	d	d
p[4]					d	d	d
p[5]						d	d
p[6]							d

Find the minimum in these pair of points. Using nested loop of 2D array:

```
 for (int i=0; i<7; i++){ // pseudo code
        for (int j=i+1; j<8; j++){
              if (distance < min) min = distance;
}} // pseudo code.
```

Demonstration Program

FindingClosestPair.java

Lab:

CombinationNumber.java

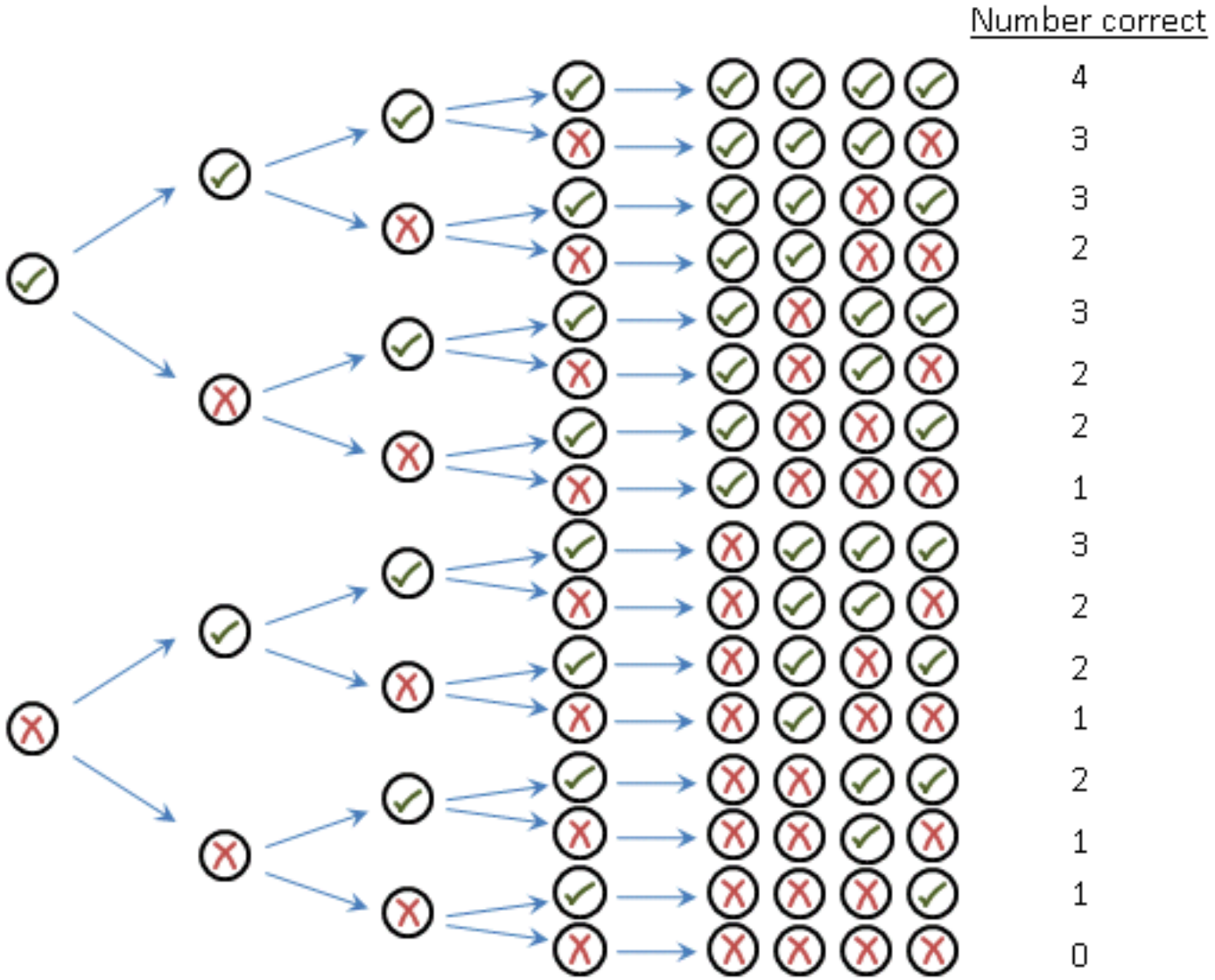
Lecture 5

Purpose of this project

- (1) Use 2-D array for a real-world calculation application.
- (2) Exercise on the 2D **index calculation** using **mapping**.
- (3) 2-D Array can also work like a method (function)
- (4) The term **Wrapper Function**.
- Wrap a function with easier interface or user-friendly interface. Or, providing extra information each time wrapper method is called.

Binomial Experiments

(Coin Tossing/Yes No Question Guessing)



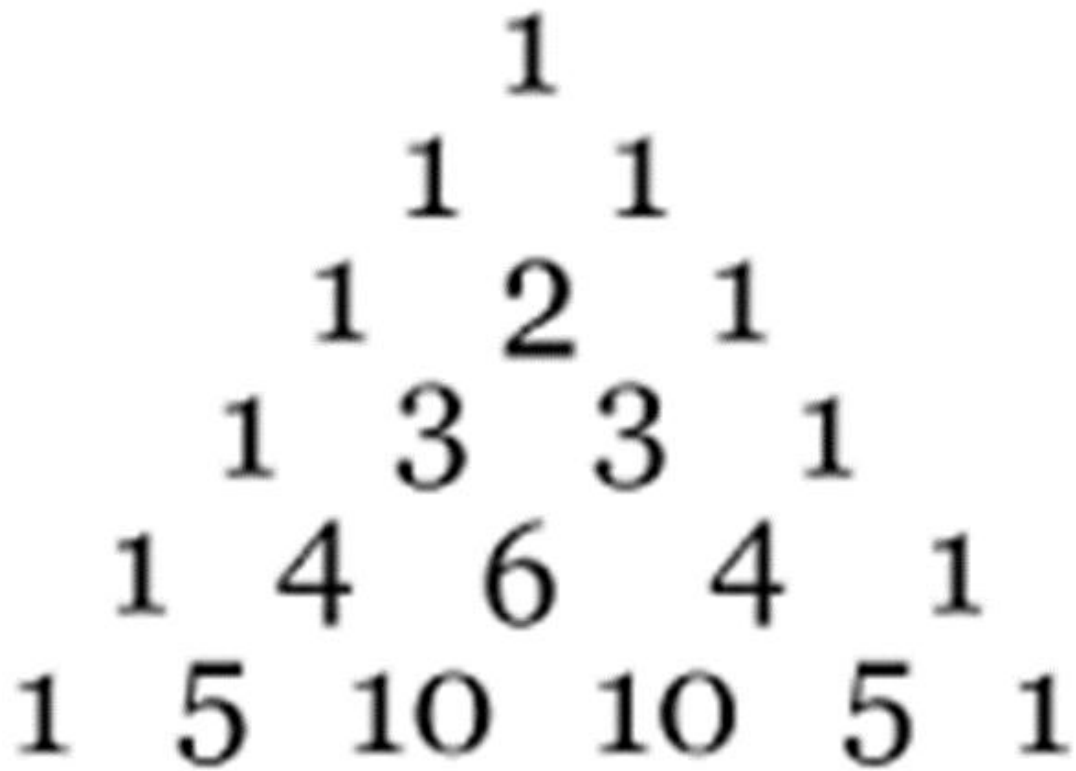
Lab Project:
Generation of a Combination Number

- In mathematics, C_m^n denotes the number of different ways that m things can be selected from n different choices. For example, if you are choosing among six desserts and are allowed to take two, the number of different combinations you could choose is C_2^6 . Here's one formula to compute this value: $$C_m^n = \frac{n!}{m!(n-m)!}$$
- This value also gives rise to an interesting recursion:
$$C_m^n = C_{m-1}^{n-1} + C_m^{n-1}$$
- **Write an iterative function to compute combinations.** Hints: when $m=1$, $C_m^n = n$ and when $n < m$, $C_m^n = 0$;

Binomial Theorem

$$
\begin{aligned}
(a+b)^0 &= 1 \\
(a+b)^1 &= a+b \\
(a+b)^2 &= a^2+2ab+b^2 \\
(a+b)^3 &= a^3+3a^2b+3ab^2+b^3 \\
(a+b)^4 &= a^4+4a^3b+6a^2b^2+4ab^3+b^4 \\
(a+b)^5 &= a^5+5a^4b+10a^3b^2+10a^2b^3+5ab^4+b^5
\end{aligned}
$$

Pascal Triangle



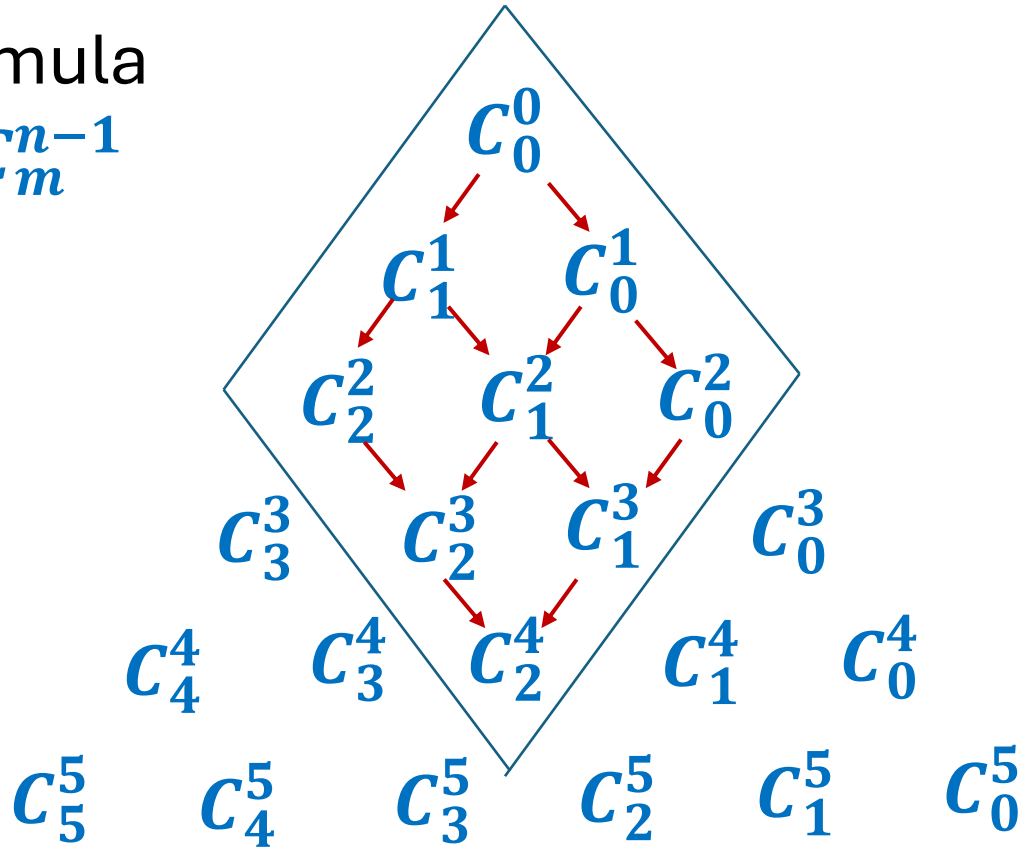
Binomial Theorem

Combination Number:

$$C_m^n = \frac{n!}{m!(n-m)!}$$

(1) Recursive Formula

$$C_m^n = C_{m-1}^{n-1} + C_m^{n-1}$$



Binomial Theorem

Mapping C to K array

Combination Number:

$$C_m^n = \frac{n!}{m!(n-m)!}$$

(1) Recursive Formula

$$C_m^n = C_{m-1}^{n-1} + C_m^{n-1}$$

(2) Mapping Rule

$$C_m^n = K_m^{n-m}$$

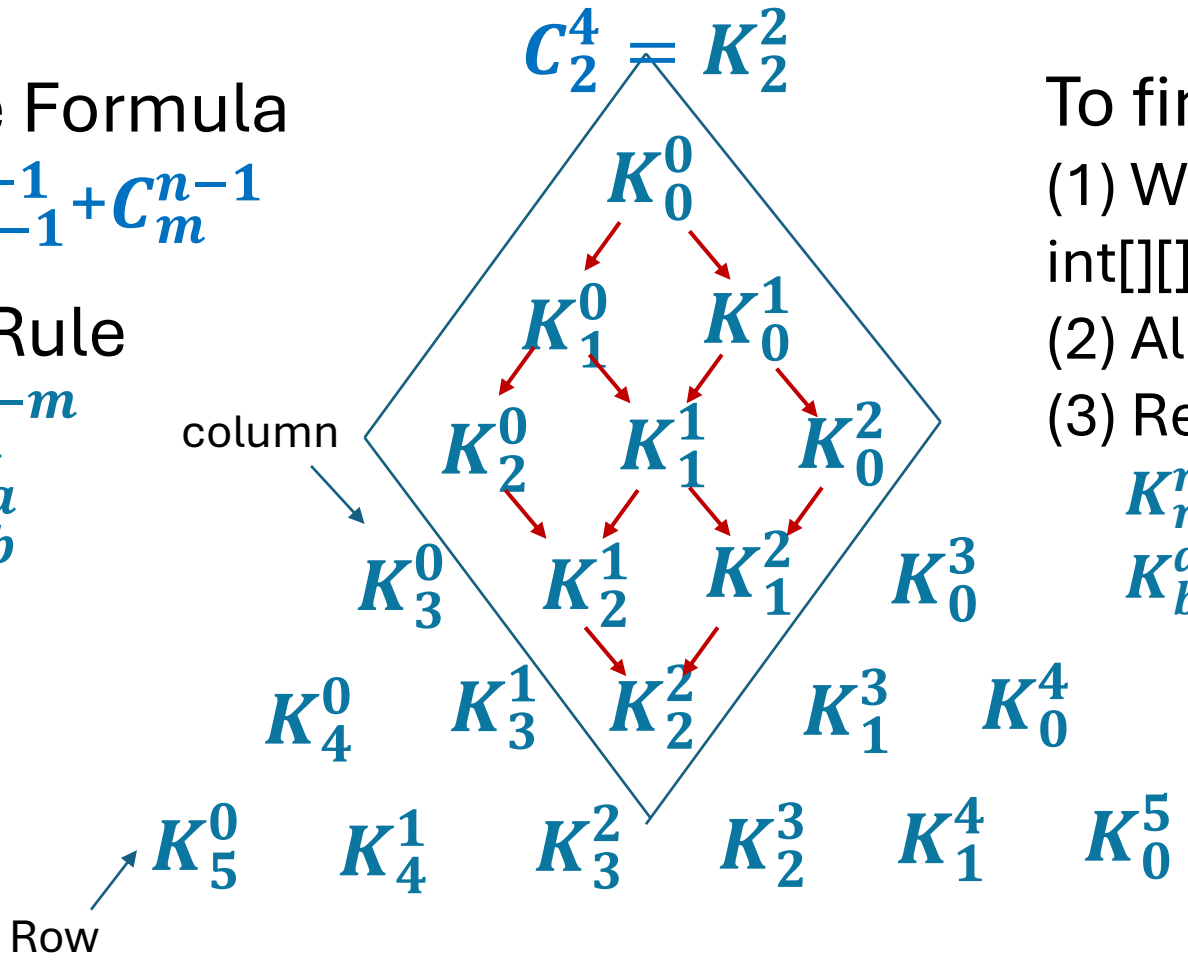
$$C_b^{a+b} = K_b^a$$

a = n-m

b = m

(a+b) = n

b = m



To find C_m^n :

(1) We need to create 2D Array:

int[][] k = new int[n-m+1][m+1];

(2) All row 0 and col 0 are 1.

(3) Recursive formula for K:

$$K_m^{n-m} = K_{m-1}^{n-m} + K_m^{n-m-1}$$

$$K_b^a = K_{b-1}^a + K_b^{a-1}$$

Pseudo Code

2D array is also a method (function)

```
public static c(int n, int m){ // also called as wrapper
function.
    Create k array of n-m+1 row and m+1 column.
    set row 0 of array k to 1.
    set col 0 of array k to 1.
    set a = n-m; b = m;
    for (int i=0; i<= a; i++)
        for (int j=0; j<= b; j++)
                k[i][j] = k[i-1][j] + k[i][j-1];
     return k[a][b];
}
```

Other Wrapper Functions:

```
public static htmlTagWrapper(String tag, String source){
    return “<”+tag+”> ”+source+” </”+tag+”>”;
}
```

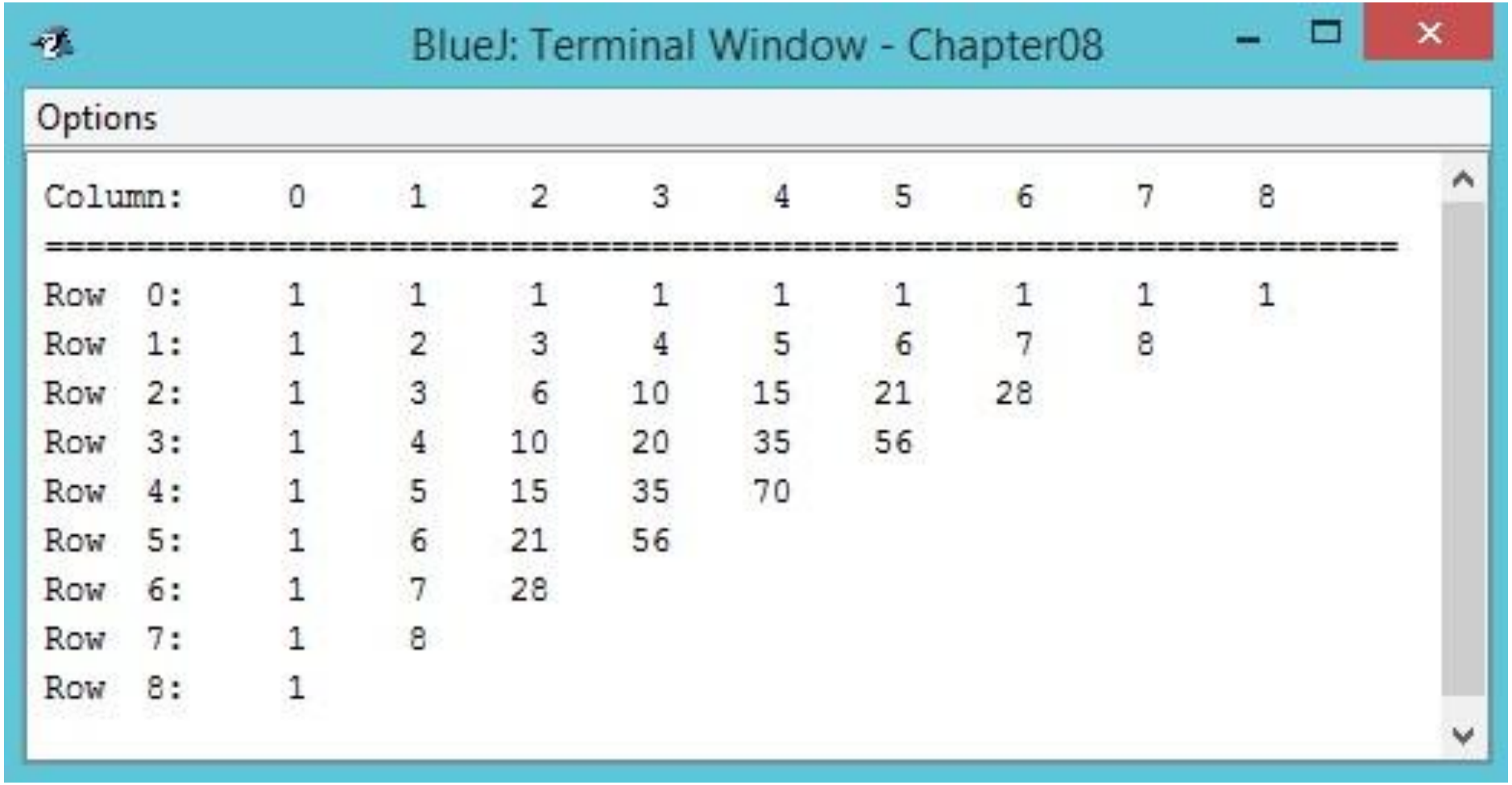
Example:

htmlTagWrapper(“p”, “This is a paragraph in HTML. ”);

Output:

 This is a paragraph in HTML.

Expected Result:



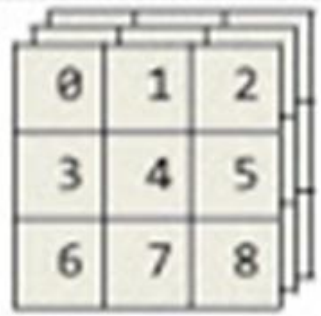
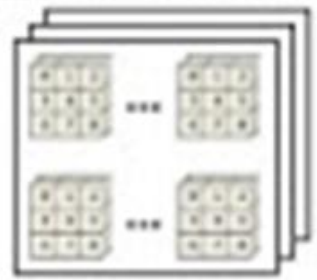
Lab

CombinationNumber.java

N-D Arrays

Lecture 6

What is an array?

Dimensions	Example	Terminology
1		Vector
2		Matrix
3		3D Array (3rd order Tensor)
N		ND Array

Multidimensional Arrays

A two-dimensional array consists of one-dimensional arrays and a three-dimensional array consists of two-dimensional arrays

- Occasionally, you will need to represent n-dimensional data structures. In Java, you can create n-dimensional arrays for any integer `n`.
- The way to declare two-dimensional array variables and create two-dimensional arrays can be generalized to declare n-dimensional array variables and create n-dimensional arrays for `n>=3`.

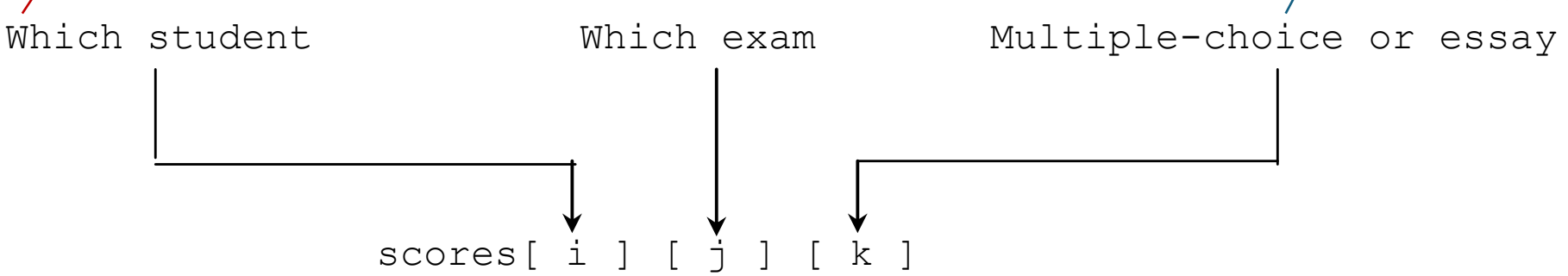
Example: Calculating Total Scores

- **Objective:** write a program that calculates the total score for students in a class. Suppose the scores are stored in a three-dimensional array named scores. The first index in scores refers to a **student**, the second refers to an **exam**, and the third refers **to the part of the exam**.
- Suppose there are 7 students, 5 exams, and each exam has two parts--the multiple-choice part and the programming part. So, scores[i][j][0] represents the score on the multiple-choice part for the i's student on the j's exam. Your program displays the total score for each student.

Multidimensional Arrays

```
double[][][] scores = {
  {{7.5, 20.5}, {9.0, 22.5}, {15, 33.5}, {13, 21.5}, {15, 2.5}},
  {{4.5, 21.5}, {9.0, 22.5}, {15, 34.5}, {12, 20.5}, {14, 9.5}},
  {{6.5, 30.5}, {9.4, 10.5}, {11, 33.5}, {11, 23.5}, {10, 2.5}},
  {{6.5, 23.5}, {9.4, 32.5}, {13, 34.5}, {11, 20.5}, {16, 7.5}},
  {{8.5, 26.5}, {9.4, 52.5}, {13, 36.5}, {13, 24.5}, {16, 2.5}},
  {{9.5, 20.5}, {9.4, 42.5}, {13, 31.5}, {12, 20.5}, {16, 6.5}}};
```

An exam: {9.0, 22.5}



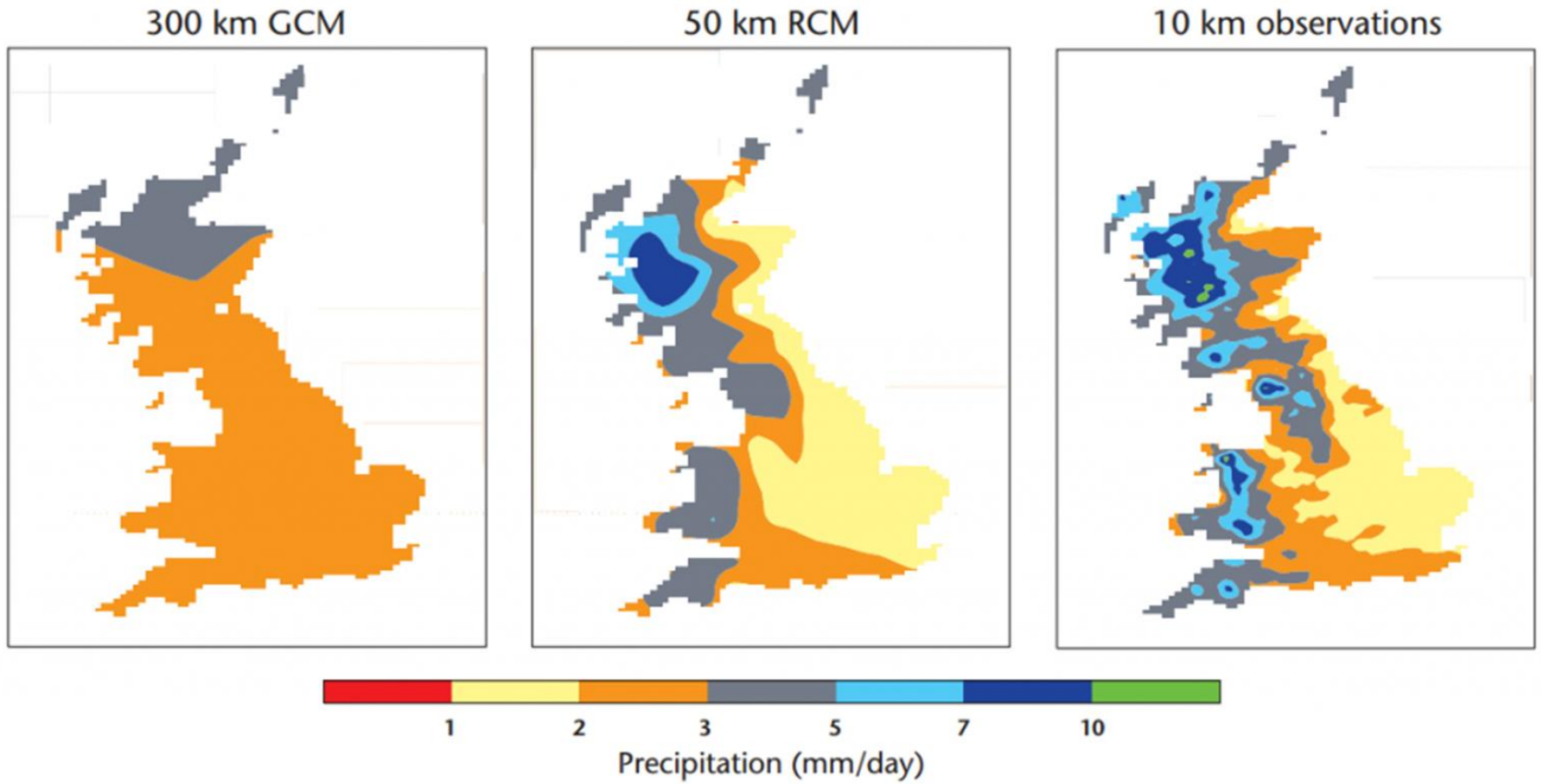
Demo Project: Weather Model

- **Global Climate Models:**
- Climate models divide the surface of the Earth into a horizontal grid, the atmosphere into vertical levels, and time into discrete timesteps.

- `GCM(x, y, h, day, hour, temperature, humidity)`

- Single_Point_CM(day, hour, temperature, humidity) // in Weather.txt

Global Climate Model (GCM) Versus Regional Climate Model (RCM)

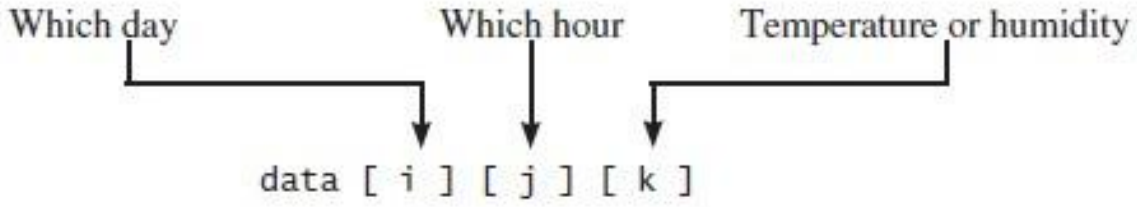


Demo Project: Weather Information

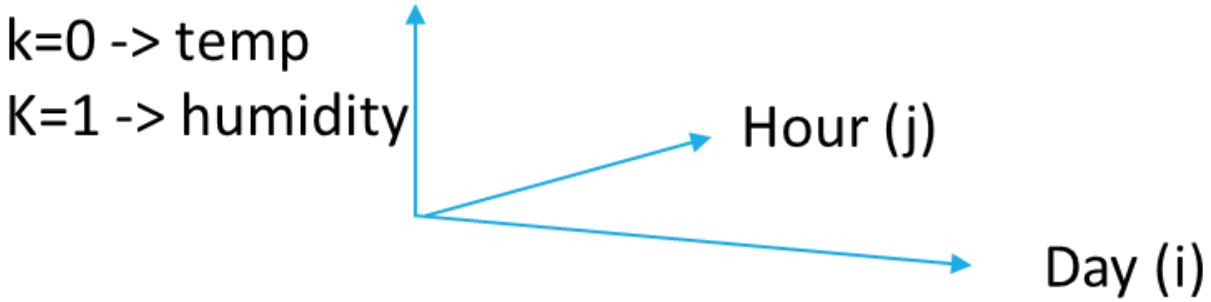
Weather.java

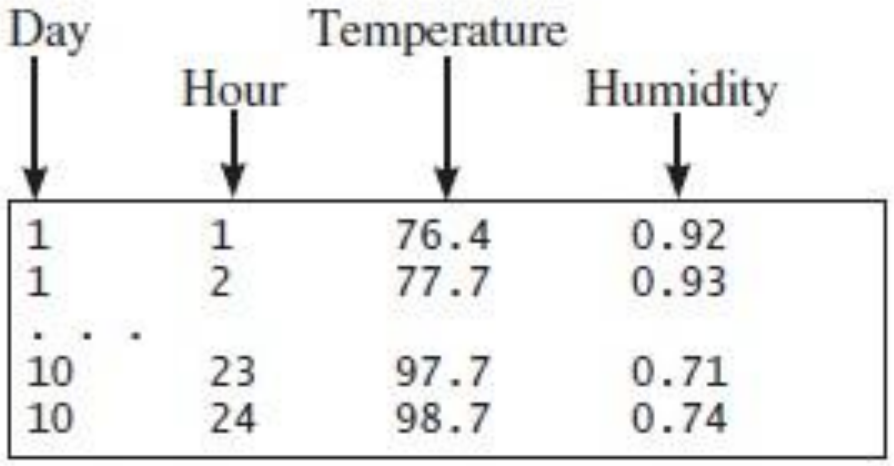
- Suppose a meteorology station records the temperature and humidity at each hour of every day and stores the data for the past ten days in a text file named **weather.txt**.
- Each line of the file consists of four numbers that indicate the day, hour, temperature, and humidity. Your task is to write a program that calculates the **average** daily temperature and humidity for the 10 days.

Data Structure

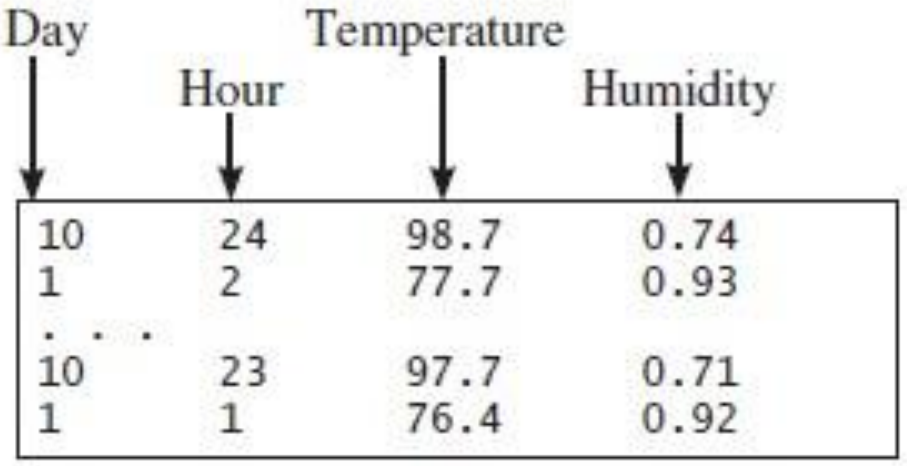


- Weather.txt:



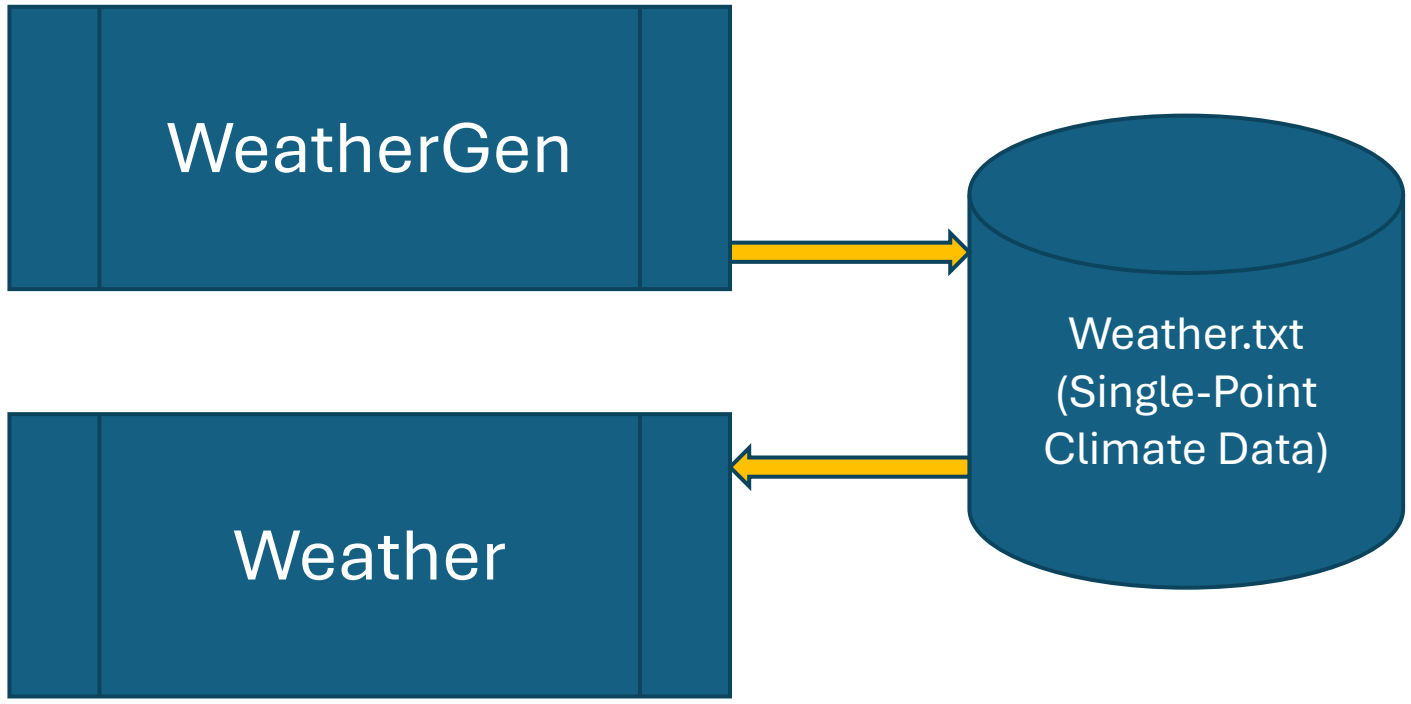


(a)



(b)

Data Flow Diagram



Demonstration Program

Weather.java

WeatherGen.java