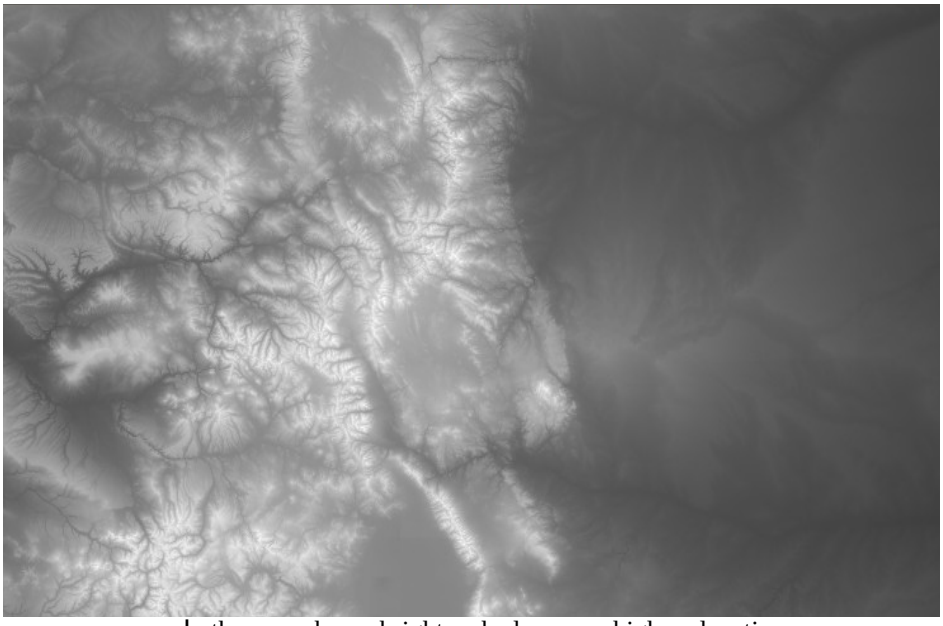
CSCI165 Computer Science II
Lab Assignment: Bit Mapped Path Finder

Objectives

- Understand, implement and process Java 2D arrays
- Understand and implement simple Java 2D graphics
- Nested loops
- Understand and implement a greedy algorithm: https://en.wikipedia.org/wiki/Greedy_algorithm

In this lab you will read a set of topographic (land elevation) data from the National Oceanic and Atmospheric Information into a 2D array. You will then use that 2D array to generate a bit mapped visualization using the Java 2D graphics library. Once the map has been generated you will write some methods to compute and visualize paths through the mountains. You will then instruct the program to select the path that has the lowest elevation change.

Background:
There are many contexts in which you want to know the most efficient way to travel over land. When traveling through mountains (let's say you're walking) perhaps you want to take the route that requires the least total change in elevation with each step you take – call it the path of least resistance. Given some topographic data it should be possible to calculate a "greedy lowest-elevation-change walk" from one side of a map to the other.



In the map above, brighter shades mean higher elevation.

A Greedy Walk

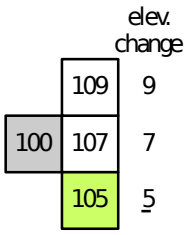
A "greedy" algorithm is one in which, in the face of too many possible choices, you make a choice that seems best at that moment. For the maps we are dealing with there are 7.24×10^{405} possible paths you could take starting from western side of the map and taking one step forward until you reach the eastern side.

3011	2900	2852	2808	2791	2818
2972	2937	2886	2860	2830	2748
2937	2959	2913	2864	2791	2742
2999	2888	2986	2910	2821	2754
2909	2816	2893	2997	2962	2798

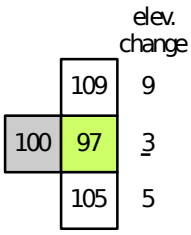
Shows a portion of the data.
Greedy path shown in green.

Since our map is in a 2D grid, we can envision a "walk" as starting in some in some cell at the left-most edge of the map (column 0) and proceeding forward by taking a "step" into one of the 3 adjacent cells in the next column over (column 1). Our "greedy walk" will assume that you will choose the cell whose elevation is closest to the elevation of the cell you're standing in. (NOTE: this might mean walking uphill or downhill).

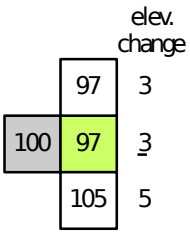
The diagrams below show a few scenarios for choosing where to take the next step. In the case of a tie with the forward position, you should always choose to go straight forward. In the case of a tie between the two non-forward locations, you should flip a coin to choose where to go.



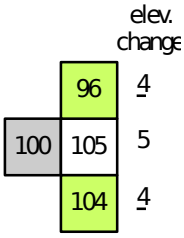
Case 1: smallest change is 5, go fwd-down



Case 2: smallest change is 3, go fwd



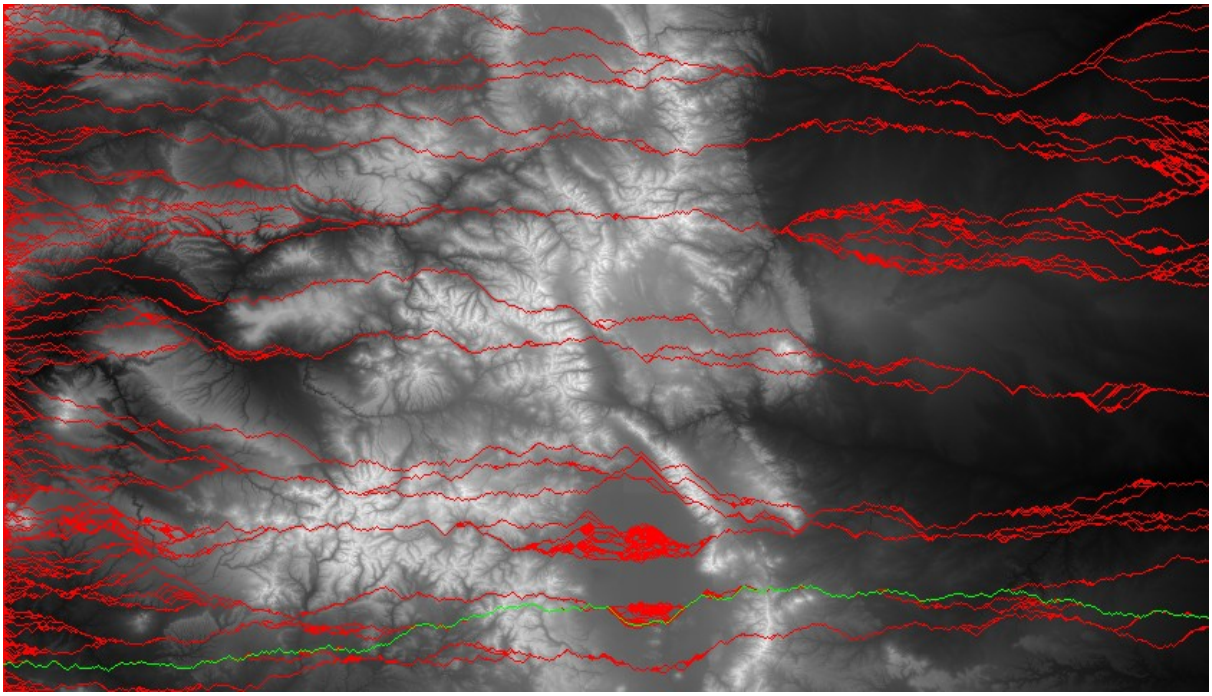
Case 3: smallest change is a tie (3), fwd is an option, so go fwd



Case 4: smallest change is a tie (4), choose randomly between fwd-up or fwd-down

Assignment Requirements

Step 1: Read the data into a 2D array
Step 2: Find min, max elevations, and other calculations on the data
Step 3: Draw the map
Step 4: Draw a lowest-elevation-change route starting from some row
Step 5: Find and draw the lowest-elevation-change route in the map (shown below in green)



To fulfill the requirements you are provided with a class and method stubs for completing parts of the project. You can make a copy of the ***Drawer.java*** file. Here is the sketch. The arguments can be modifed to fit your needs. You do not have to adhere to this structure 100%.

public class MapDataDrawer
//a class for maintaining a 2D array of ints representing a topographic map

MapDataDrawer(String filename, int rows, int cols)
//read data from given file into a 2D array

int findMin()
//return the minimum value in the map

int findMax()
//return the max value in the map

void drawMap(Graphics g)
//draw this map in grey scale using given graphics context

int indexOfMinRow(int col)
//given a column, find the index of the row with min elevation
// return row number of

int drawLowestElevPath(Graphics g, int row)
//draw the lowest elevation path starting from the given row
// return total elev change from the path

int indexOfLowestElevPath(Graphics g)
//find the lowest elev change path in the map
//return the row it starts on

Step 1 – Read the data into a 2D array
Your first goal is to read the values into a private 2D array of ints in the MapDataDrawer class. The constructor of the class should read the given data file into a new 2D array of ints maintained as a private variable of the class.

The data
The data is a plain ascii text file from NOAA representing the average elevations of patches of land (roughly 700x700 meters) in the US. The data file included with the project, ***Colorado_844x408.dat***, is the elevation data for most of the state of Colorado. The data comes as one large, space-separated list of integers. There are 403,200 integers representing a 480-row by 844-col grid. Each integer is the average elevation in meters of each cell in the grid.

In the constructor:

- Instantiate a new 2D array of ints of the appropriate size. The size should be determined by parsing the name of the provided elevation file. The file name should be provided as a command line argument and be structured like above
  - **Descriptor_COLSxROWS.dat**
  - You should be able to provide any file and have your program respond accordingly.

- Read the ints out of the data file (the data are listed in **row-major** order).

- **WARNING:** The data are given as a continuous stream of numbers - there are no line breaks in the file, so you can't use nextLine(). You need to use Scanner's nextInt() method to read each subsequent in. You also probably want to write nested loops to cover the exact rows/cols (480/844) needed. The loop control variables should be populated with the row/column data parsed from the file name

After you've written the constructor**, test it with the debugger.** Make sure that you're actually reading data into the 2D array. Do a sanity check by looking at a specific row and col and comparing with a friend, or against the original data itself.

Step 2 – Find the min and max values

In order to draw the map you need to find the min and max values in the map first. Implement the **findMin()** and **findMax()** methods. These should return the smallest and largest values respectively in the 2D array. You'll need to write code that scans the entire array and keeps track of the smallest and largest things found so far.

Test these functions independently first to make sure you're getting decent values. Maybe check with a friend to see if they are getting the same thing.

Step 3 – Draw the map

Implement the **drawMap**(Graphics) method of the class. The method will be passed the Graphics object you should use to do the drawing.

The method "draws" the 2D array of ints as a "but map" with each cell in the array defining the color gradient to color the "pixel". This can be viewed as a series of filled 1x1 rectangles with the color set to a gray scale value between white and black.

RGB Colors: https://www.rapidtables.com/web/color/RGB_Color.html

The shade of gray should be scaled to the elevation of the map. If each of RGB values are the same, you'll get a shade of gray. Thus, there are 256 possible shades of gray from black (0,0,0) to middle gray (128,128,128), to white (255,255,255)

To make the shade of gray**,** you should use the min and max values in the 2D array to scale each int to a value between 0 and 255 inclusive. (**Note:** this requires math! Think about it.) Once you have found your value between 0 and 255, call you need to set the fill color just before drawing the rectangle.

int c = //calculated grayscale value

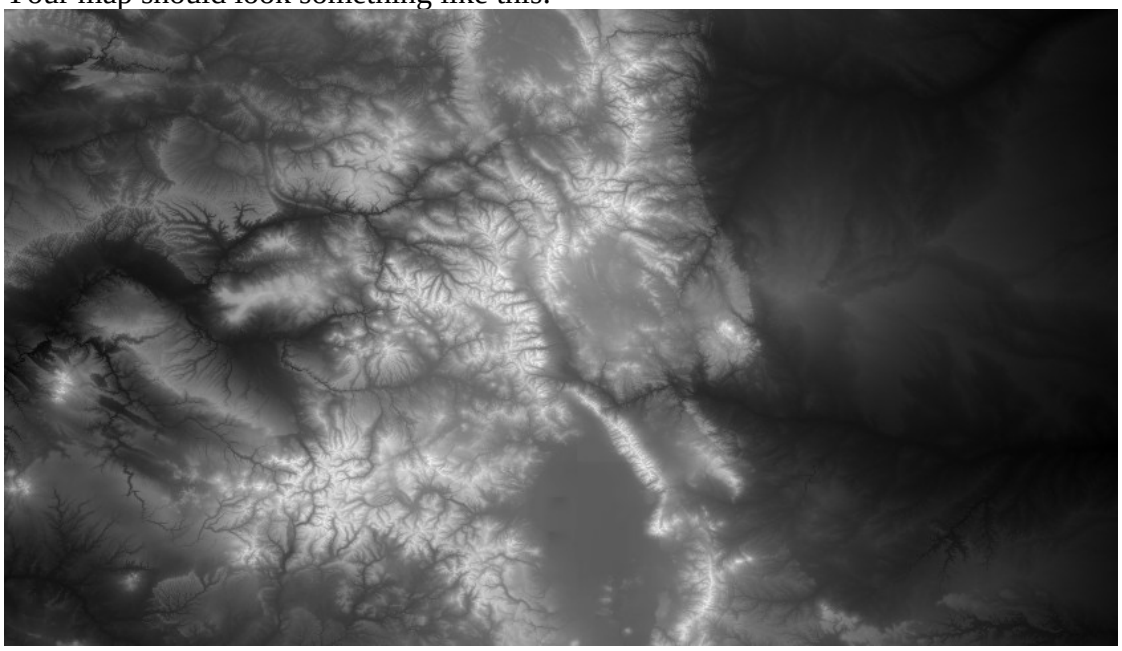
g.setColor(new Color(c, c, c));

g.fillRect(x,y,1,1)

WARNING: the 2D array represents the data in row-major order (that's how it came out of the data file). But the graphics are drawn in column-major order x,y format. Thus, remember to flip row and col (or x and y) if using them as variables to access the array or draw the graphics

grid[row][col] g.fillRect(col,row,1,1)
or
grid[y][x] g.fillRect(x,y,1,1)

This step is easier to test because there is graphical output to verify you're doing it right. Your map should look something like this:



Step 4 – Draw a lowest-elevation-change path from some row

Implement the **drawLowestElevPath**(Graphics, startRow) method. Note that this method does two things:

1. It draws the path
2. it calculates and returns to the total elevation change on that path.

The method should draw a line by drawing 1x1 filled rects in a different color on top of the existing drawing. The path should be drawn going West-to-East, starting from the given row using the greedy lowest-elevation-change technique described earlier.

You will need to do the following things in some order.

1. Starting from the given row, and column 0, color it green (or whatever color you want to draw your path).
2. Write a loop that generates every possible column across the map from 1 to 840 (you start at column 0, but column 1 is the first column you need to make choice about where to step). For each column you will decide which row to take your next "step" to – fwd, fwd-and-up, or fwd-and-down - using the greedy choice strategy described.
3. Color the chosen location to step to green (or whatever color you choose).
4. Use a variable that keeps track of the 'current row' you're on, and update it each time you take a step forward – row may stay the same, or go up or down by 1 depending how you walk.
5. Use Math.abs(…) to get the absolute value of the difference between two elevations.
6. Continue finding the lowest neighboring cell and coloring it green as you go.

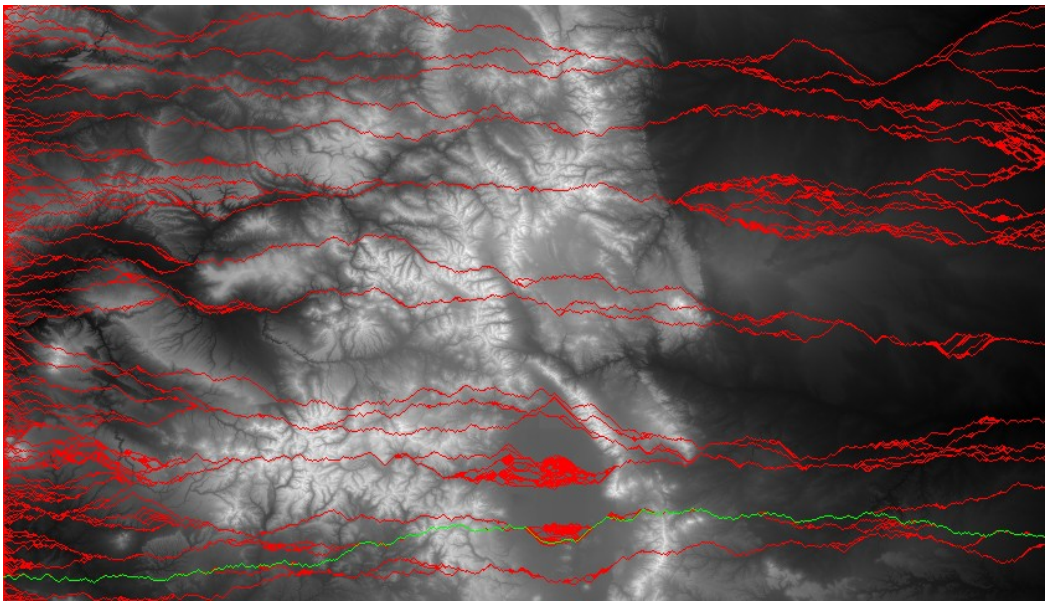
7. Keep a running total of the total elevation change that would be 'experienced' by a person walking this path. Since we consider an elevation change the absolute value (i.e. going 'uphill' 10 meters is the same amount of change as going 'downhill' 10 meters) this running total will be non-decreasing and will end up being a pretty large positive number

When you're done you should see a line tracing the lowest elevation-change path from west to east.

Step 5 – find the lowest elevation path for the whole map

Implement the **indexOfLowestElevPath**() method which finds the overall lowest-elevation-change path and returns the row it starts on.

You will find the lowest-elevation-change route by noting that the method you wrote in step 4 returns the total elevation change for a path starting at a given row. If you write a loop that generates every possible starting row from 0 to 480, and call your method using each possible starting row, you should find the lowest route for the whole map. (Since that method also draws all of the routes it's good feedback that the method is running properly.) You might end up with something that looks like this:



Sanity Check:

NOTE: The greedy walk should always produce a *slightly* different path due to the fact that you are flipping a coin in some cases to determine which direction to go.

The best greedy walk for the Colorado map should return a total elevation change somewhere around 16,000 +/- 1000 (meters). The best path should start somewhere close to the southern edge of the map, something between row 460 and 475 or so.

Above and Beyond

Path Finding

Note that our greedy lowest-elevation-change algorithm is flawed. It is not guaranteed to find the absolute lowest elevation change route from west to east since our decisions are limited to what's in front of us.

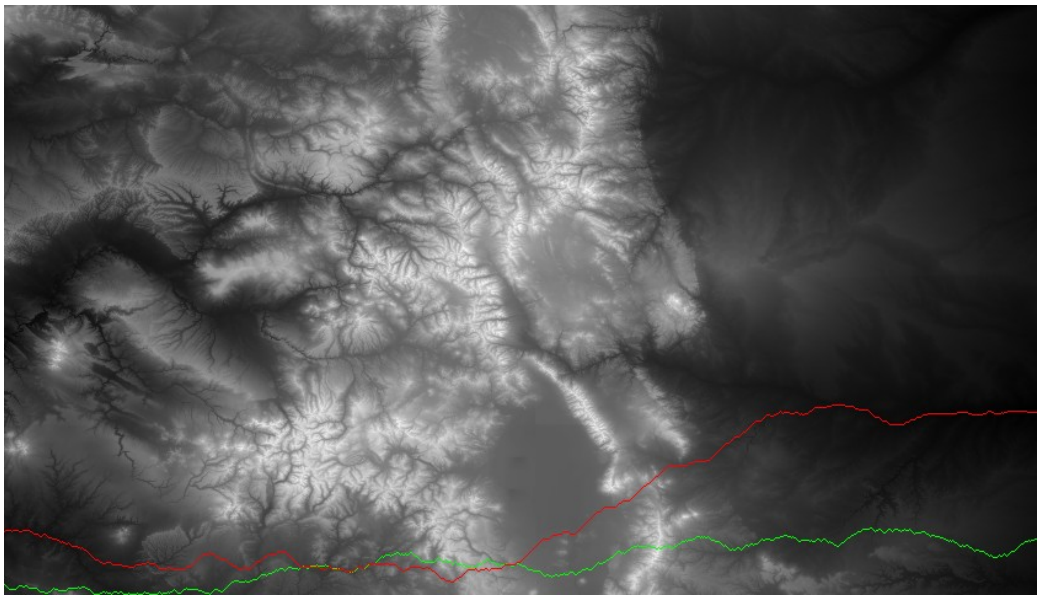
- Another, only slightly more complicated way to do a greedy walk is to start at an arbitrary x,y location in the map and do a greedy walk to the east from that point and a greedy walk to the west from that point. Using this method you could calculate the lowest elevation-change route that passes through every possible x,y coordinate. (Note, this will take some time to calculate…might not want to draw it live).

- A different kind of path you might want to follow in the mountains is to travel the path that stays as low as possible, elevation-wise, regardless of the change. Think of this as a greedy algorithm that always prefers to go downhill if possible, and uphill as little as possible. You can use a greedy method for this by always choosing to step to the location with the lowest elevation, not necessarily the lowest change in elevation. Show a comparison of these two paths.

- Write a method that finds, and highlights, the lowest elevation point for each possible column in the map. Compare that to the lowest elevation path you calculated for the problem and see If any of your paths pass through that point. If you do a greedy walk going east and west, from each of those points, do you end up finding a better elevation-change route?

- Do your walk considering more than the three forward locations. You could consider the 5, or even 7 surrounding locations. This can get pretty tricky: to do this you need to keep track of which direction you are heading, or where your last step was, so that you don't back track.

- There are many shortest path algorithms that are beyond the scope of this class. If you are curious, research them.



In essence, It is possible to compute <u>all</u> of the possible paths from west-to-east, using a separate 2D array to keep track of the best cumulative elevation change possible for each cell in the grid. You construct this grid column-by-column "moving" from west-to-east and choosing the best of three possible values to put into each cell - since each cell can be arrived at from up to three different locations in the previous column, you need to choose which of the three elevation-changes affects the cumulative total the least, and put that value in the cell.

Since that grid of best values does not tell you the path you need to follow to realize those small elevation changes, you need to maintain another 2D array in parallel, in which you store the row index that should be traveled through to achieve the best path. The best path can then be reconstructed by walking backwards and following the row values.

The best possible path gives a total elevation change of 7,056 meters (fully half of the best greedy walk) and should start around row 428.

Graphics

- You could also shade the pixels you draw for the path to indicate their relative elevations. You could get the shading for "free" by using the alpha channel of the color you select.
- Do a drawing of the mountain in colors other than a monochromatic scale. This would give you more than 256 shades of color to work with. For example, what if you shaded the lower elevations green (for lush valleys) and the highest elevations some sort of rock color brown/tan. To do this arithmetically you need to look up how to 'interpolate' colors.