CS1110 Fall 2009 Assignment A6. Images. Due Sat., 14 Nov, 11:59pm on the CMS

0. Introduction

This assignment deals with .jpg images. You will learn about how images are stored; write code to transpose images; and learn about filtering images. You will learn how a text message can be hidden in an image. You will see a little bit about how GUIS (Graphical User Interfaces) are constructed in Java. Finally, you will have practice with loops and one- and two-dimensional arrays.

Download *either* file a6.zip *or* the files indicated on the course website and put them into a new folder. Two images are included. Put everything in the same folder. To get an idea of what the program does, do this:

(1) Open file `ImageGUI` in DrJava and compile it.

(2) In the Interactions pane, type this: `j= new ImageGUI();` A dialog window will open. Navigate to a folder that contains a jpg file and select it. A window will open, with two versions of the image, some buttons, and a text area. The left image will not change; it is the original image. The right image will change as you click buttons.

(3) See what buttons `invert` and `hor reflect` do. After any series of clicks on these, you can always click button `restore` to get back the original file.

(4) You can try buttons `transpose`, `ver reflect`, and `filter out`, but they won't work until you write code to make them work.

You can use procedure `ImageGUI.writeImage` to save the modified pictures on your hard drive.

We discuss the classes in this assignment and also images. You don't have to learn all this by heart, but you would do well to study the code, being conscious of how precise the specs are and how well the Java code is written. Section 7 explains what you have to do for this assignment, and Section 8 explains what you have to turn in.

1. Separation of concerns

It is important to organize the parts of a program in a logical and coherent way such that it is clear what each part is responsible for and such that interactions between parts are kept reasonable. The larger and more complicated the task of a program, the more important it is to have good organization.

This program has two main functions: manipulating an image and providing a GUI. These two issues should be separated as much as possible in the program.

An object of class `java.awt.Image` maintains an image. Our own class `ImageArray` maintains an image as a one-dimensional array of pixels, storing the pixels of the real two-dimensional array in row-major order, i.e. first the elements of row 0, then the elements of row 1, then the elements of row 2, etc. `ImageArray` provides methods for manipulating the image, allowing a user to process the pixels of an image row by row, column by column, or without regard to the order.

Class `ImageProcessor` provides methods for transforming the image, maintained as an `ImageArray`. `ImageProcessor` knows nothing about the GUI; it simply calculates. It has fields that contain (the name of) the original and the transformed `ImageArray`.

Class `ImagePanel` provides part of the GUI. A subclass of `JPanel`, it can display an image through its method `paint`. When an image is changed in any way, the corresponding `JPanel` object has to be notified so that it can revise the size of the panel; updating the image and providing this notification are the purposes of method `changeImageTo`.

Class `ImageGUI` provides the GUI. It places buttons and `ImagePanel`s in the window, and it "listens" to button clicks and acts accordingly, calling appropriate methods in `ImageProcessor`, then calling on an `ImagePanel` to revise its view, and finally repainting the GUI.

2. Class Image and class ImageArray

An instance of class `Image` can contain a jpg image (or some other formats as well). Just how the image is stored is not our concern; the class hides such details from us. Abstractly, the image consists of a rectangular array of pixels (picture elements), where each pixel entry is an integer that describes the color of the pixel. We show a 3-by-4 array below, with 3 rows and 4 columns, where each `Eij` is a pixel.

```
E00  E01  E02  E03
E10  E11  E12  E13
E20  E21  E22  E23
```

An image with `r` rows and `c` columns could be placed in an **`int`**`[][]` array `b[0..r-1][0..c-1]`. Instead, however, class `ImageArray` maintains the pixels in a one-dimensional array `rmoArray[0..r*c-1]`. For the 3-by-4 image shown above, array `rmoArray` would contain the elements in row-major order:

```
E00, E01, E02, E03, E10, E11, E12, E13, E20, …
```

Class `ImageArray` provides the representation of an image in its array `rmoArray`, along with methods for dealing with it. You can change the image by calling its methods `getPixel(row,col)`, `setPixel(row, col, v)`, and `SwapPixels(a,b,i,j)`. So, for a variable **`im`** of class `ImageArray`, to set a pixel to `v`, instead of writing something like `im[h,k]= v;` write `im.setPixel(h,k,v);`. You can also reference pixels in row-major order in a one-dimensional array, using methods `getPixel(p)` and `setPixel(p,v)`. That's all you need to know in order to manipulate images in this assignment.

Here's more info on class `ImageArray`. The first constructor has these statements in it:

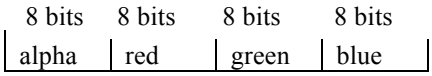
```
rmoArray= new int[r*c];
…
PixelGrabber pg= new PixelGrabber(im,0,0,c,r,rmoArray,0,c);
…
pg.grabPixels();
```

This code stores in `pg` an instance of class `PixelGrabber` that has associated image **`im`** with our array `rmoArray`. The third statement, `pg.grabPixels();`, stores the pixels of the image in `rmoArray`.

3. Pixels and the RGB system

Your monitor uses the RGB (Red-Green-Blue) system for images. Each RGB component is given by a number in the range 0..255 (8 bits). Black is represented by (0, 0, 0), red by (255, 0, 0), green by (0, 255, 0), blue by (0, 0, 255), and white by (255, 255, 255). The number of RGB colors is 2^{24} =16,777,216.

A pixel is stored in a 32-bit (4 byte) word (memory location). The red, green, and blue components each take 8 bits. The remaining 8 bits are used for the "alpha channel", which is used as a mask to make certain areas of the image transparent —in those software applications that use it. We will not change the alpha channel of a pixel in this assignment. The elements of a pixel are stored in a 32-bit word like this:



Suppose we have the green component (in binary) `g = 01101111` and a blue component `b = 00000111`, and suppose we want to put them next to each other in a single integer, so that it looks like this in binary:

```
0110111100000111
```

This number can be computed using `g*2`^{8} `+ b`, but this calculation is inefficient. Java has an instruction that *shifts* bits to the left, filling the vacated spots with `0`'s. We give three examples, using 16-bit binary numbers.

```
0000000001101111 << 1   is   0000000011011110
0000000001101111 << 2   is   0000000110111100
0000000001101111 << 8   is   0110111100000000
```

Secondly, operation `|` can be used to "or" individual bits together:

```
        0110111100000000 |                  0011 |
        0000000010111110                    1010
is      0110111110111110              is    1011
```

Therefore, we can put an alpha component `alpha` and red-green-blue components `(r, g, b)` together into a single 32-bit **int** value —a pixel— using this expression:

```
(alpha << 24) | (r << 16) | (g << 8) | b
```

Take a look at method `ImageProcessor.invert`. For each pixel, the method extracts the 4 components of the pixel, inverts the red, green, and blue components (e.g. the inversion of `red` is `255 - red`), reconstructs the pixel using the above formula, and stores the new pixel back in the image.

4. Class ImagePanel

Read this section with class `ImagePanel` open in DrJava. A `JPanel` is a component that can be placed in a `JFrame`. We want a `JPanel` that will contain one Image. So, we make `ImagePanel` extend `JPanel`.

Field `image` of `ImagePanel` contains (the name of) the image object. The constructor places a value in `image` and also sets the size and "preferred size" of the `ImagePanel` to the dimensions of the image —this preferred size is used by the system to determine the size of the `JFrame` when laying out the window.

Method `paint` is important. Whenever the system wants to redraw the panel (perhaps it was covered and is now no longer covered), the system calls method `paint`, which calls `g.drawImage` to draw the image.

Finally, method `changeImageTo` is called whenever our program determines that the image has been changed, e.g. after inverting the image. Take a look at the method body.

How does one learn to write all this code properly? When faced with doing something like this, most people will start with other programs that do something similar and modify them to fit their needs (as we did).

5. Class ImageGUI

A `JFrame` is associated with a window on your monitor. Since we want a window (that contains two versions of an image), class `ImageGUI` extends `JFrame`. Take a look at the following components of class `ImageGUI` (there are others, which you need not look at now).

Fields `originalPanel` and `currentPanel` contain the panels for the original and manipulated images.

Constructors: There are two constructors. One is given an image. The other has no parameters: it gets the image using a dialog with the user, where the user can navigate on their hard drive and choose which image to work with. This is similar to obtaining a file to read, which you learn about in a lab.

Method `setUp`. Both constructors call this private method. The method puts the buttons into the `JFrame` —we'll learn about this later. It then adds a labeled text area, which you will use later. Then, provided there is an image, it creates two panels with the image in them and adds them to the `JFrame`, using the call `add (BorderLayout.EAST, imagebox);`. It creates an instance of class `ImageProcessor`, which will contain methods to manipulate the object. Finally, it fixes the window location, makes the `JFrame` visible, and "packs" and repaints it.

The call of method `setDefaultCloseOperation` near the end of `setUp` fixes the small buttons in the `JFrame` so that clicking the "close" button causes the window to disappear and the program to terminate.

Read Chapter 17 of the text for more information on placing components in a `JFrame`. The most efficient and enjoyable way to learn about GUIs is to listen to lectures on the *ProgramLive* CD.

Methods to manipulate the image. At the bottom of class `ImageGUI` are methods to (1) restore, invert, and transpose the image; (2) filter an image, (3) hide and retrieve a message in the image, and (4) write an image to your hard drive. They are placed here to make it easy to perform these functions using the Interactions pane. They work by calling methods in class `ImageProcessor`, several of which you have to write.

Methods to make the buttons available to the program. A set of methods are used to connect the clicking of a button on the window to the program. You don't have to look at these. We'll give some idea of how they work later.

6. Class ImageProcessor

Class `ImageProcessor` provides all the methods for manipulating the image given to it as an `ImageArray` in the constructor. The constructor stores the image in field `originalIm` and stores a *copy* of it in `currentIm`.

As the image is manipulated, object `currentIm` changes. It can be restored to its original by copying field `originalIm` into `currentIm`. That's what procedure `restore` (near the end of the class) does.

Procedures `invert`, `hreflect`, and `restore` are complete. Procedure `invert` inverts the image (makes a negative out of a positive, and vice versa). Notice how it processes each pixel —first retrieving it, then computing what its new color components should be, and finally placing the changed pixel back into `currentIm`.

7. The methods you will write. Implement the methods in class `ImageProcessor` as explained below.

7A. Implement method `vreflect`. This method should reflect the image around its vertical middle. Look at method `hreflect` to get an idea about how to do it.

7B. Implement method `transpose`. Below is an array. To its right is its transpose: each row `k` of the original array becomes column `k` in its transpose.

array	**transpose**
01 02 03 04	01 06 11
06 07 08 09	02 07 12
11 12 13 14	03 08 13
	04 09 14

The transpose algorithm is fairly easy to write in terms of two-dimensional arrays. However, the algorithms will be a bit more complicated when the arrays involved are arrays of pixels making up an image. We suggest that, before writing the code to manipulate the images, you write a static function to produce the transpose of a two-dimensional integer array `b[0..r-1, 0..c-1]`, as well as a procedure to print (in the Interactions pane) a rectangular array in order to help you debug your work. This practice makes code writing easier. You will then simply translate your code into the `ImageArray` framework.

The comments in the body of `transpose` should help you write the body. READ THEM CAREFULY. In addition, use procedure `ImageProcessor.hreflect` as a model for accessing the elements of an `ImageArray`.

7C. Implement method `filterOut`. In this method, you change each pixel of the image depending on the value of parameter `c`. You either filter out a single color (removing red, green, or blue), or remove all color by setting each of the three color components (red, green, blue) to the average of the original red, green, and blue values —this produces a gray-scale image. (Handy quick test: white pixels stay white and black pixels stay black.)

This manipulation requires that you extract the alpha, red, green, and blue components from each pixel, construct the new pixel value, and store it. Look at procedure `invert` to see how this is done.

In determining what parameter `c` is, do NOT use integer constants 0, 1, 2, and 3; instead use the static final fields `GRAY`, `RED`, `GREEN`, and `BLUE`. Use mnemonic names rather than constants, so that the program remains readable.

7D. Steganography, according to Wikipedia (en.wikipedia.org/wiki/Steganography), "is the art and science of writing hidden messages in such a way that no one apart from the intended recipient even realizes there is a hidden message." In contrast, in cryptography, the existence of the message is not disguised but the content is obscured. Quite often, steganography deals with messages hidden in pictures.

To hide a message, each character of the message is hidden in one or two pixels of an image by modifying the red, green, and blue values for the pixel(s) so slightly that the change is not noticeable.

Each character is represented using the American Standard Code for Information Interchange (ASCII) as a three-digit integer. We allow only characters that can be represented in ASCII —all the obvious characters you can type on your keyboard are ASCII characters. See page 6.5 of the ProgramLive CD for a discussion of ASCII.

For the normal letters, digits, and other keyboard characters like `$` and `@`, you can get its ASCII representation by casting the char to **`int`**. For example, `(int)'B'` evaluates to the integer 66, and `(int)'k'` evaluates to 107.

We can hide character `'k'` in a pixel whose RGB values are 199, 222, and 142 by changing each color component so that its least significant digit contains a digit of the integer representation 107 of `'k'`:

Original pixel				**Pixel with 'k' hidden**		
Red	Green	Blue	hide `'k'`, which is 107	Red	Green	Blue
199	222	142	⟶	19**1**	22**0**	14**7**

This change in each pixel is so slight that it will not —cannot— be noticed just by looking at the image.

Decoding the message, the reverse process, requires extracting the last digit of each color value of a pixel and forming the ASCII value of a character from the three extracted values. In the above diagram to the right, extract 1, 0, and 7 to form 107, and cast this integer to **`char`**.

Extracting the message does *not change the image*. The message stays in the image forever.

Three problems for you to solve. You will write code to store a message `m` in the pixels of an image in row-major order, starting with pixel 0, 1, 2, … Think about the following issues and solve them.

(1) You need some way to recognize that the image actually contains a message. Thus, you need to place something in pixels 0, 1, 2, … that has very little chance of appearing in a real image. You can't ever be *sure* that an image without a message doesn't start with those pixels, but the chances should be extremely small. This beginning marker should use at least two pixels.

(2) You have to know where the message ends. You can do this in several ways —place the length of the message in the first pixels in some way (how many pixels can that take?), put some unused character at the end of the message, or use some other scheme. You may assume that the message has fewer than one million characters.

(3) The largest value of a color component (e.g. blue) is 255. Suppose the blue component is 252 and you try to hide 107 in this pixel; the blue component should be changed to 257, but this impossible because a color components are ≤ 255. Think about this problem, come up with at least two ways to solve the problem, and implement one of them.

As you can see, this part of the assignment is less defined than the previous ones. *You* get to solve some little problems yourself. Part of this assignment will be to document and discuss your solutions.

Your task on part 7D

(a) Decide how you will solve the problems mentioned in points 1..3 given above. As you design and implement this part, write a short essay that documents at least 2 solutions to each of the 3 problems mentioned above, discusses their advantages and disadvantages, and indicates what your solutions are. Advantages could be: easiest to implement, fewest number of pixels used in hiding an image, least time spent in hiding a message —whatever. When you are finished with this assignment, insert this essay as a comment at the beginning of class `ImageProcessor`.

Feel free to discuss points 1..3 with the course staff. They will not tell you *how* to solve these problems. But they will discuss your ideas with you.

(b) Complete the body of procedures `hide` and `reveal` in class `ImageProcessor`. These two methods will hide a message and reveal the message in the jpg image. When you design method `reveal`, make sure it attempts to extract the message only if its presence is detected. Feel free to introduce other methods as they are needed, but make them private because they are not to be called by a user, but only by your program.

Debugging hide and reveal can be difficult. We give you some hints on this at the end of this document.

A note on static inner classes

In class a few times, we created a class simply to collect a few variables together as fields and to provide methods to manipulate them. Class `Pair`, which contains fields "hits" and "misses", was one example of this.

If you feel the need to use such a class when writing part 7D, then declare it as a private static class at the end of class `ImageProcessor` —after the last method but before the "}" that ends the body of the class. Yes, you can declare "inner classes" this way, but make them static, so there is only one copy of it, and private, so that other classes can't use it.

Please introduce such a class ONLY if necessary, and talk to an instructor or a TA before you do it. Part 7D can be done without it, and most people will not need this additional class.

8. What to submit

Start early, because you are sure to have questions! Waiting until the deadline will cause you frustration and lack of understanding, instead of the fun that should be felt in completing this assignment. Complete the bodies of procedures `vreflect`, `transpose`, `filterOut`, `hide`, and `reveal` in class `ImageProcessor`. Don't change anything else (other than writing your private helper methods and, if necessary and after discussion, any static inner classes) —don't declare new fields in the class and don't change any of the other classes.

Insert your essay (see the beginning of part 7D) into file `ImageProcessor` and submit the file on the CMS.

Writing, testing and debugging hide and reveal

Methods `hide` and `reveal` can be difficult to debug. Here some hints to help you.

1. We encourage writing other methods (perhaps helper methods) besides `hide` and `reveal`. You get to decide which ones to write as you design and implement this assignment. Be sure to specify each method appropriately in a comment before it.
2. It will be difficult to use a JUnit testing class here, because it will be difficult to get it to access a picture appropriately. You do not have to use one.
3. Use function `ImageArray.toString(pixel)` to get a readable String representation of a pixel.
4. Do *not* assume that you can debug simply by calling `hide` and then `reveal` to see whether the message comes out correctly. The best thing to do is to write method `hide` and debug it before going on to `reveal`.
5. In the methods that you write, insert `System.out.println(…);` statements to print out information, so that you can see what your code is doing. This is the easiest way to determine whether your code is working correctly. But you will have to continually change these statements in order to keep the amount of output to something manageable. When you submit the assignment, please remove these statements as a courtesy to the graders (who already have a lot of code to read).
6. Start with extremely short messages to hide —1, 2, or 3 characters— and first check that the initial pixels, which are supposed to indicate that a message is hidden, are correct.
7. Try hiding and revealing a long message —1000, 2000, 5,000 characters. Notice any difference in the time to hide and the time to reveal? Can you figure out why? Can you change your code to make them the same (you don't have to do this). We'll discuss this in class at the appropriate time.