CS1110 Fall 2011 Assignment A6. Images. Due 16 November, 11:59pm on the CMS

0. Introduction

Read this *entire* document carefully. Budget your time wisely. Don't wait until the day before the deadline to do this assignment. Start now and do a little work every day (practice with loops/invariants will help you on the prelim).

This assignment deals with images. You will

1. Learn how images are stored in memory
2. Write methods to manipulate images, getting practice with for-loops and 1- and 2-dimensional arrays
3. Write methods to "undetectably" hide and reveal a secret text message in an image
4. Learn a little bit about constructing GUIs (Graphical User Interfaces) in Java
5. Read and understand previously written code
6. Get practice with stepwise refinement, such as through writing your own helper methods
7. Learn about using constants (final variables) to represent “magic numbers” in a more mnemonic fashion

Download *either* file a6.zip *or* the other files for A6 given on the course website and put them into a new folder. Several images are included. Put everything in the same folder. To get an idea of what the program does, do this:

(1) Open file `ImageGUI.java` 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 JPEG (.jpg) file (or any other kind of image file that Java knows how to read) 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`, `transpose`, and `hor reflect` do. After any series of clicks on these, you can always click button `restore` to get back the original file.

(5) You can try buttons `ver reflect`, `fuzzify`, `put In Jail`, etc., but they won’t work unless you write code to make them work.

We discuss the classes in this handout. 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 the Java code is written. Section 7 explains what you have to do for this assignment. Section 8 explains what you have to turn in.

Grouping. You may work with one other student. If you do, group yourselves on the CMS at least 1 week before the due date. You are expected to do the work together. Separating the work into two parts, doing the parts independently, and then merging the work is a violation of academic integrity. Any writing of Java code should be done while sitting together, with one person typing and the other person helping. Take turns doing the typing.

Academic Integrity. We expect the work you submit to be yours (or your group’s) alone. It is a violation of academic integrity to be in possession of or to read the code produced by someone else, either in this class or in previous classes, or to show your code (in any format) to other students in the class. Please don’t do that. If we find someone has done this, we will prosecute according to Cornell’s Code of Academic Integrity.

1. Separation of concerns

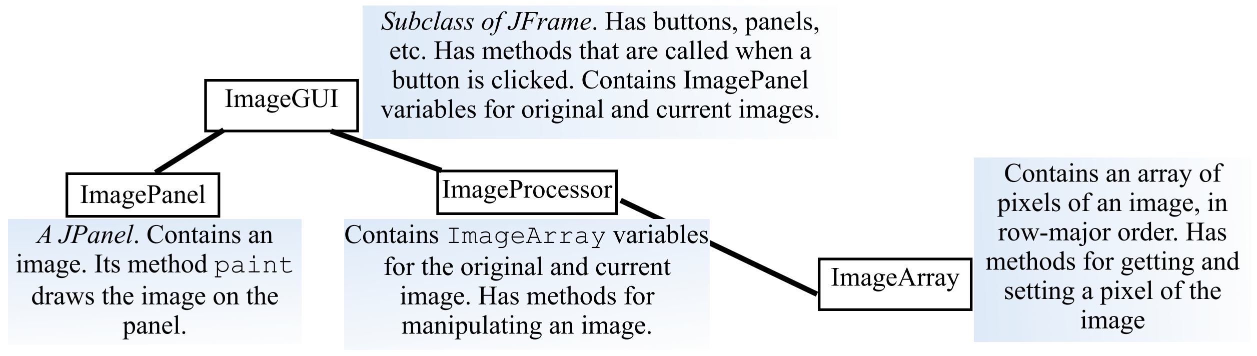
It is important to organize the parts of a program in a logical and coherent way, so that it is clear what each part is responsible for and so that interactions between parts are kept reasonable. The larger and more complicated the task of a program, the more important it is to have good organization.

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.

Look at the diagram on the next page. 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 conceptually 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, which is maintained as an `ImageArray`. `ImageProcessor` knows nothing about the GUI; it simply calculates. It has fields that contain (the names 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 to revise the panel; updating the image and providing this notification are done by method `changeImageTo`.


ImageGUI
Subclass of JFrame. Has buttons, panels, etc. Has methods that are called when a button is clicked. Contains ImagePanel variables for original and current images.
ImagePanel
A JPanel. Contains an image. Its method paint draws the image on the panel.
ImageProcessor
Contains ImageArray variables for the original and current image. Has methods for manipulating an image.
ImageArray
Contains an array of pixels of an image, in row-major order. Has methods for getting and setting a pixel of the image

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 `Image-Panel` to revise its image, and finally repainting the GUI.

2. Class Image and class ImageArray

An instance of class `java.awt.Image` can contain an image (such as might be read in from a .jpg or other format of image file). Just how the image is stored is not our concern; the class hides such details. 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, class `ImageArray` maintains the pixels in a one-dimensional array `rmoArr[0..r*c-1]`. For the 3-by-4 image shown above, array `rmoArr` would contain the elements in row-major order:

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

Class `ImageArray` provides the representation of an image in its array `rmoArr`, along with methods for dealing with it. You can get the value of an individual pixel with `getPixel(row,col)`. You can change the image using its methods `setPixel(row,col,v)` and `SwapPixels(a,b,i,j)`. So, for a variable `im` of class `Im-ageArray`, to set a pixel to `v`, instead of writing `im[h,k]= v;` write `im.setPixel(h,k,v);`. You can also reference pixels as 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.

3. Pixels and the RGB system

Your monitor uses the RGB (Red-Green-Blue) color 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). Since this system uses 8 bits for each of the three colors of a pixel, it's called "24-bit RGB color", and the number of distinct 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:

8 bits	8 bits	8 bits	8 bits
alpha	red	green	blue

Suppose we have the green component (in binary) `g = 01101111` and 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 operation 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 |          and      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, 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` object. 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 called whenever the system wants to redraw the panel (perhaps it was covered and is now no longer covered); our method `paint` 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 read the API specifications and then 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 learned about in lab.

Method setUp. Both constructors call this private method. The method puts the buttons into the `JFrame` (using two arrays and a loop to streamline some of the repetitive stuff) —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 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 (although if you do, note the use of assert statements to make the programmer's job less prone to errors). 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 state by copying field `originalIm` into `currentIm`. That's what procedure `restore` (near the end of the class) does.

Procedures `invert`, `hreflect`, `transpose`, and `restore` are complete. Procedure `invert` inverts the image (makes a negative out of a positive, and vice versa). Note how it processes each pixel—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.

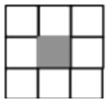
Before you write any code, read the notes on writing, testing, and debugging on page 6.

Y*ou must write a complete and thorough specification of any method you introduce*. It is best to write the spec *before* you write the method body, because it helps *you* as you program. This is standard practice in this course. It is a severe error not to do so, and points will be deducted for missing or inappropriate specifications.

You need not write loop invariants, and if you do, we will not grade them. But we encourage you to write them for each loop so that you get used to thinking in terms of the invariant and the four loopy questions.

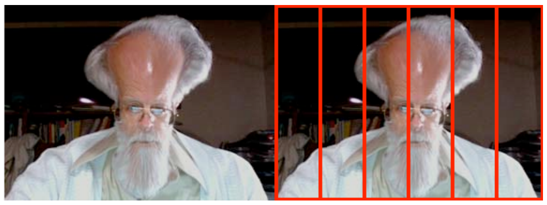
7A. Implement method `vreflect`. This method should reflect the image around its vertical middle. Look at method `hreflect` to get an idea about how to do it.

7B. Implement method `fuzzify`. You do *not* have to implement fuzzify, and if you do, it will not be graded. This method replaces each pixel of the current image (except those on the edge) by the average of itself and its 8 neighbors—i.e. replace the red component by the average of the red components, and similarly for the blue and green components. *Don't* average the alpha component or otherwise change it. Follow the directions given in the java file. Look at method `invert` to see how to pick out the color components from a pixel and to build a new pixel.



As in `transpose`, the method will have two nested loops, and each iteration of the inner loop will process one pixel. Do not write all the code to process a pixel in the inner loop; instead, write another, private, procedure that processes the pixel and, in the body of the inner loop, call the new procedure. This is done to keep each method simple and short. Also, you can initially stub in the private method (e.g. have it set the pixel to carnelian, RGB (179, 27, 27) to facilitate constructing and testing one part of your code at a time, in a top-down, stepwise-refined fashion.

7C. Implement method putInJail. To the right you see the effect of clicking button *put in jail*: —drawing the red boundary and the vertical bars. This will happen when you implement method `putInJail` according to its specifications.



We have given you helper procedure drawHBar; use it. In the same way, implement a private procedure to draw a vertical bar. Don't forget its specification.

When finished, open a picture, click buttons *put in jail*, transpose, and then *put in jail* again for a nice effect.

7D. Implement method `monochromify`. In this method, change each pixel of the image depending on the value of parameter `c`. First convert the image to grayscale by calculating the overall brightness of each pixel using a combination of the original red, green, and blue values, defined by:

brightness = 0.3 * red + 0.6 * green + 0.1 * blue

and then setting each of the three color components (red, green, and blue) to this brightness value. To simulate a sepia toned photograph (a process used to increase the longevity of photographic prints), further darken the green and blue channels, setting green to 0.6 * brightness and blue to 0.4 * brightness, producing a reddish-brown tone. (Handy quick test: white pixels stay white for grayscale, and black pixels stay black for both grayscale and sepia tone.)

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 and 1; instead use the static final fields `GRAY`, and `SEPIA` (the names of variables holding constants are chosen to be all-capitals by convention). Use these mnemonic names rather than the actual numbers so that the program remains readable.

7E. Implement method `vignette`. Camera lenses, particularly ones from the early days of photography, block some of the light that should be focused at the edges of a photograph, producing a darkening toward the corners of the image known as "vignetting", which is a distinctive feature of old photographs. In this method, you simulate this effect using a simple formula: pixel intensities (in red, green, and blue separately) are multiplied by 1 – (distance to center)^2 / (half of image diagonal)^2. Like the monochromification, this requires unpacking and repacking the color components of each pixel, but for this operation you will need to know the row and column of the pixel you are processing, so that you can compute its distance from the center of the image.

7F. 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 of the pixel(s) so slightly that the change is not noticeable to the eye.

Each character is represented using the American Standard Code for Information Interchange (ASCII) as a three-digit integer. We allow only ASCII characters —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 or look on the web.

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 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	$\longrightarrow$	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 hide characters of 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 hide characters in pixels 0, 1, 2, … that have little chance of appearing in a real image. You can't be *sure* that an image without a message doesn't start with the pixels resulting from hiding the characters, but the chances should be extremely small. The beginning marker should use at least two pixels.

(2) You have to know where the message ends. You can do this in several ways —hide the length of the message in the first pixels in some way (how many pixels can that take?), hide 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 7F

(a) Decide how you will solve the problems mentioned in points 1..3 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: 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`.

Here are three points.

(1) Make the essay readable. For example, we should not have to scroll horizontally to read it, and it should have paragraphs —15 lines of uninterrupted text is not readable.

(2) Do not explain anything in terms of what if-statements and assignments you would write and the like. Your reasoning should be at a higher level than that.

(3) At the end of the essay, state precisely the format of a hidden message: what the beginning marker is, etc.

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) First, complete (and test) function `getPixels(n)` in class `ImageProcessor`. In the hints in section 9, we talk about debugging `hide` before writing `reveal`. From experience, we know that students who don't do this can have great difficulty with this part of the assignment and don't even complete it correctly. Therefore, we have added this extra method to your assignment for your use in debugging. After writing this function, you can type this in the interactions pane to print the first 9 pixels (we also give the output):

```
b= new ImageGUI();
b.getPixels(9)
"pixels of current image: (104, 160, 161) (101, 157, 156) (098, 153, 147) (100, 154, 141) (108, 154, 141)
                          (101, 142, 124) (075, 108, 089) (045, 072, 053) (041, 059, 045)"
```

You can look at function `ImageGUI.getPixels` and see that it calls the one you wrote.

(c) Complete the body of procedures `hide` and `reveal` in class `ImageProcessor`. These two methods will hide a message and reveal the message in the 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 to be called not 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.

8. What to submit

Start early, because you are sure to have questions! Waiting until the deadline will cause frustration and lack of understanding, instead of the fun you could have in completing this assignment. Complete the bodies of procedures `vreflect`, `putInJail`, `monochromify`, `vignette`, `hide`, and `reveal` in class `ImageProcessor`. Don't change anything else (other than writing private helper methods that you write) —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 7E) into file `ImageProcessor` and submit the file on the CMS.

9. About the save button

Clicking button `Save` saves the image in the current directory with name foobar.png (if the file does not exist). You can hide a message, save, and then reload the image with the message still there. If we had used extension jpg, it would not have worked, because with the jpg format, the image may be altered when saving it; it is a lossy format. Procedure `writeImage` at the end of `ImageProcessor.java` writes the file.

10. Hints on writing, testing and debugging

1. For a method that consists of several steps, do not write the whole method and then compile and test. Generally you will have many syntax errors and you will waste time. Instead, compile after every line of code you write, and test what you have done if it is feasible to do so.
2. Using a JUnit testing class is difficult because you can't easily get access a picture. You do not have to use one.
3. Use function `ImageArray.toString(pixel)` to get a readable String representation of a pixel.
4. Use `println` statements so that you can see what your code is doing. This is the easiest way to determine whether your code is working correctly. You will have to continually change these statements in order to keep the amount of output to something manageable. Before submitting the assignment, remove these statements as a courtesy to the graders —points will be deducted if you do not remove them.
5. Hide and reveal:
   a. We encourage writing helper methods to keep code simple and short in `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.
   b. Do *not* assume that you can debug simply by calling `hide` and then `reveal` to see whether the message comes out correctly. Instead, debug method `hide` and then write and debug `reveal`.
   c. Start with short messages to hide (1, 2, or 3 characters) and check that the pixels contain the message.
   d. When `hide` and `reveal` are done, try hiding and revealing a long message —1,000, 2,000, 5,000 characters. Notice any difference in the time to hide and the time to reveal? Can you figure out why? We'll discuss this in class at the appropriate time.