Project 5: Pixel Magic

Purpose

- to be able to design a solution to a real-world practical problem from scratch.
- to be able to represent the information in the problem domain using the constructs available in a programming language.
- to be able to decompose a solution into functions.
- to be able to use what we have learned in this course to build a program that can solve a real-world problem.
- to be able to unit-test as well as integration-test a program.

You may not use any image utility modules available for Python nor any other modules, built-in functions and constructs that have not been covered in this course. In addition to the restriction, you may not use sort() and sorted().

Description

For this project, you will write functions that transform an image in the following ways:

1. Adjusting colors to reveal a hidden picture.
2. Darkening colors to produce a fading effect.
3. Apply a filter to an image to remove salt-and-pepper noises.

Download the image files from Canvas.

Image File Format

The P3 (.ppm) format is a text-based format (meaning that it is readable text) that defines an image as a sequence of pixels beginning with the top-left pixel and stored in row order (i.e. every pixel in a row is stored in left-to-right order and before any pixel in the next row).

A file conforming to the P3 format begins with header information. The header consists of the characters `P3`, the integer width of the image (in pixels), the integer height of the image, and the maximum value for a color component (we will use `255` for this value). Immediately following the header is the color information for each pixel. A pixel's color is represented by three integers (whole numbers without a decimal point) denoting the red, green, and blue components (in that order). The following example shows how a file would look if it contained an image initially with one blue pixel, one red pixel, and one green pixel.

```
P3
3 1
255
```

```
0 0 255
255 0 0
0 255 0
...
```

The top-left pixel is said to be at location `<0, 0>` and the bottom-right at location at `<width - 1, height - 1>`.

Testing

You are required to write at least 3 tests using the unittest module for each helper function that takes an argument / arguments and returns a value (i.e. is not an I/O function). Since we are emphasizing test-driven development, you should write tests for each function first. In doing so, you will have a better understanding as to what the functions take as input and produce as output, which makes writing the function definitions easier. Create **pixelmagic_tests.py** and write your tests in the file.

Viewing PPM Images

To view the images produced by your program, use the following tools:

- If you are using Mac, use Preview (if you double click your image file, it will be opened by Preview).
- If you are using other OS including Windows and Unix, you can upload your image file to this web image viewer http://www.cs.rhodes.edu/welshc/COMP141_F16/ppmReader.html , or download and install GIMP(https://www.gimp.org/downloads/) and open the file with GIMP.

Output image files containing pixel values with decimal points (i.e. floating point numbers such as 1.0 and 1.5.) are not acceptable. Please make sure that all pixel values are integers, otherwise 5 points will be docked per image.

Implementation

Your program must support the following three modes: ‘decode’, ‘fade’, and ‘denoise’. In this project, you can decide how you want to decompose your program into functions. However, it is required that you create at least three functions that take some arguments and return some values.

The functions described below are recommended but not required for you to implement. In the functions below, pixels refers to a list of lists of integers, in which each inner list (representing a single pixel) contains 3 integers, one for each color value. Create **pixelmagic.py** and write your program in the file.

`main()`

`find_image(pixels)`

Returns decoded pixels. Corresponds to the filter mode ‘decode’.

`fade_image(pixels, width, row, col, radius)`

Returns faded pixels. Corresponds to the filter mode ‘fade’.

`denoise_image(pixels, width, height, reach, beta)`

Returns denoiseed pixels. Corresponds to the filter mode ‘denoise’.

Error and Usage Messages

Regardless of the filter mode, print one of the following error messages when its corresponding condition is true.

- If either the filter mode or image path is not provided, your program must print:

  ```
  Usage: python3 pixelmagic.py <mode> <image>
  ```

- If the image argument is provided but cannot be opened (e.g. does not exist), your program must print (replacing the blank with the name of the file given):

  ```
  Error: Unable to Open ____
  ```

- If the mode argument is not decode, fade, or denoise, your program must print:

  ```
  Error: Invalid Mode
  ```

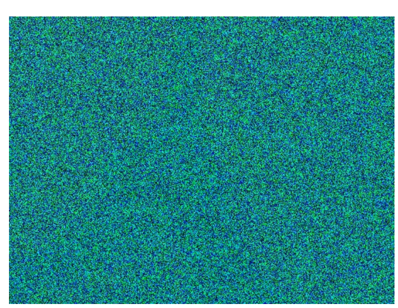
For all other messages to display, see the corresponding sections below.

1. Hidden Image: ‘decode’ mode (20 points.)

This program will get you started with the core functionality of processing a P3 image file. Your program must take a single command-line argument that specifies the name of the input image file. Your program shall print this message if the user fails to type the image file name.

```
Usage: python3 pixelmagic.py decode <image>
```

It will output the decoded image to a file named `decoded.ppm`. The output must be a valid P3 image file; do not forget to write the required header information to it.



The puzzle image hides a real image behind a mess of random pixels. In reality, the image is hidden in the red components of the pixels. Decode the image by increasing the value of the red component by multiplying it by `10` without allowing the resulting value to pass the maximum value of `255`. In addition, set the

green and blue components equal to the new red value. Shown below is the hidden image; it will be obvious once you have properly decoded the puzzle image (a black & white image of a famous landmark in Paris).
Output image files containing pixel values with decimal points (i.e. floating point numbers such as 1.0 and 1.5.) are not acceptable. Please make sure that all pixel values are integers, otherwise 5 points will be docked per image.

2. Fade: ‘fade’ mode (30 points.)

This program is a relatively minor modification of the previous program. In addition to the filter mode and file name, it must take three additional command-line integer arguments (in the following order):

1. The row (y-coordinate) position of the fade center
2. The column (x-coordinate) position of the fade center
3. The fade radius

These three arguments may be assumed to be integers. If any of these arguments are not provided, an appropriate usage message must be printed to the terminal and the program should terminate. This message is as follows:

```
Usage: python3 pixelmagic.py fade <image> <row> <col> <radius>
```

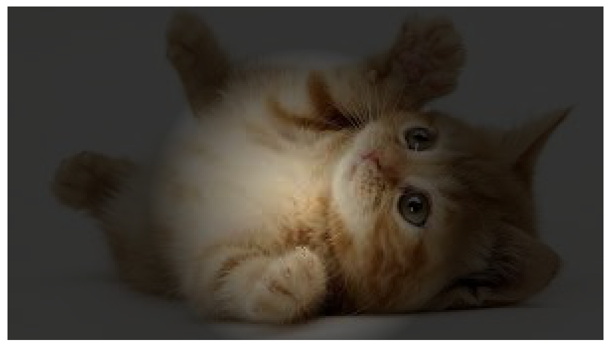
Your program will output the faded image to a file named `faded.ppm`, which must be a valid P3 image file; do not forget to write the required header information to it.

This program will transform pixel values based on their distance from a specified point (this point may fall outside of the image). The row and column coordinates specified on the command-line give the point and the radius is used to control the fading.

For each pixel, compute the distance from the pixel location to the specified point. Scale (multiply) the color components of the pixel by:

```
(radius - distance) / radius
```

Do not use a scale value below `0.2`, which prevents very dark borders around the image).
Output image files containing pixel values with decimal points (i.e. floating point numbers such as 1.0 and 1.5.) are not acceptable. Please make sure that all pixel values are integers, otherwise 5 points will be docked per image.

	
`original image`	`row = 300, col = 450, radius = 300`
	
`original image`	`row = 100, col = 150, radius = 100`

3. Noise Reduction: ‘denoise’ mode (50 points)

In ‘denoise’ mode, your program is required to apply the median filter to remove salt-and-pepper noise from a black-and-white image. The **median filter** is a non-linear digital filtering technique, often used to remove noise from an image or signal. The median filter removes noise by replacing a pixel with the median of its neighboring pixels within a window of a certain size.

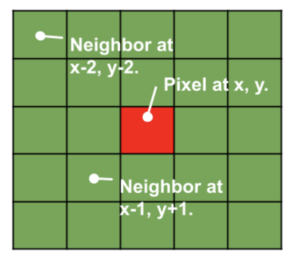
In addition to the filter mode and file name, your program must take two additional command-line numerical arguments (in the following order):

1. An integer argument, "neighbor reach", to be used to determine the window of the filter (this argument is optional and will be used to determine which neighbor pixels to consider in the averaging calculation, as discussed below) Use a default value of `2` if the user does not specify it.
2. A floating-point number argument, “beta” value, to be used to determine if a pixel must be replaced or not. Use a default value of `0.2` if the user does not specify it. In order for the user to specify the beta value, they must specify the reach value as well.

```
Usage: python3 pixelmagic.py denoise <image> <reach> <beta>
```

Your program must output the filtered image to a file named `denoised.ppm`. You need to take a deep copy of the original pixels, then modify the copy. But you must use the original pixels to compute the median. You may use copy.deepcopy():e.g. new_pixels = copy.deepcopy(pixels). You need to import the copy module. The output must be a valid P3 ppm image file; do not forget to write the required header information to it.
Your program will filter the image by computing, for each pixel, the median of nearby pixels (more precisely, the median over one color component of the nearby pixels. It does not matter which color channel value you use because you are only required to filter a black and white image, but in the following explanation, we assume that you use the red channel. In a black and white image, all three channels have the same value.). A pixel's replacement color will be determined by the colors of the pixels within a specified "neighbor reach". The default "neighbor reach" is `2` (but this can be modified by a command-line argument as discussed previously). Thus, a pixel's replacement color will be determined by the colors of the pixels within two pixels to the left or right and within two pixels above or below (this will form a square window of size 5). The following diagram is meant to help illustrate.

This diagram shows how to compute the color for the pixel in the center (the red element). Its neighbors (within a reach of 2) are all of the green elements. The pixels outside of this 5x5 square are not considered in the replacement color calculation for this pixel. To compute the color for the center pixel, sort the red values of pixels in the window in ascending order. Some pixels will not have the full complement of neighbors (such as those on or near the edge of the image). In these cases, just find the median of the existing neighbors (i.e. those within the bounds of the image).



Suppose that the pixel values of neighbors are put in a list called neighbors:
neighbors = [123,225,231,...,45]
Then the list must be sorted first. **You may not use Python's builtin list.sort() method nor the sorted() function.** Implement either the selection sort or the insertion sort. You may copy your sorting function from Project 4 and paste it into pixelmagic.py file.
After sorting, the list will look as follows:
neighbors = [45,...,123,225,231]
Then you can pick the median pixel value with the following code:
med = neighbors[len(neighbors)//2]
The pixel's new RGB values shall be all set to the same value: med.

To avoid replacing a good pixel unnecessarily, you will use the beta value to determine if the pixel needs to be replaced by using the following formula:
if abs(original - median) / (original + 0.1) > beta, replace the original pixel with the median value. This is to ensure that only outlier pixels will be replaced. As you can see, a higher beta value leaves some noise but the image remains sharp.

Output image files containing pixel values with decimal points (i.e. floating point numbers such as 1.0 and 1.5.) are not acceptable. Please make sure that all pixel values are integers, otherwise 5 points will be docked per image.

		
`original image with noise`	`reach = 1, beta = 0.15`	`reach = 2, beta = 0.1`
		
`reach = 2, beta = 0.15`	`reach = 2, beta = 0.2`	

As you will notice, this process takes a very long time (more than 50 seconds). It is because the sorting algorithms we have learned in this course, selection sort and insertion sort, are not very efficient. If you have extra time to work on more challenging problems, you might want to implement a very efficient sorting algorithm called merge sort, https://runestone.academy/runestone/books/published/pythonds/SortSearch/TheMergeSort.html .

Submission

Upload `pixelmagic.py`, `pixelmagic_tests.py`, and at least three generated images (.ppm files. At least one image for each mode.) to Canvas.
The style of your code will be checked with **pylint** and up to 10 points might be docked from your grade.

You may not resubmit your work after the due date nor after it has been graded. So, make sure you run your program on your computer and test if it really works.

`Open the image files produced by your program with image viewer software.`
`Also, open the image files produced by your program with vim and make sure that the files do not contain any decimal points.`

Rubric

- Part 1: 20 points only if your implementation produces the correct image. -5 points if you fail to submit the decoded image as a ppm file.
  - Up to 10 points if the decoded image shows the correct structure clearly but has some erroneous artifacts.
- Part 2: 30 points only if your implementation produces the correct image. -10 points if you fail to submit the two faded images, cat and NY, as ppm files (-5 per image).
  - Up to 15 points if the faded image shows a decent faded image but has some erroneous artifacts.
- Part 3: 50 points only if your implementation produces the correct image. -5 points if you fail to submit at least one denoised image of Barbara as a ppm file.
  - between 5 and 40 points depending on the quality of the denoised image and the correctness of the program if the denoised image shows a decent denoised image but has some erroneous artifacts.

In addition to the above rubric, the following rubric will be applied to the entire assignment.

- The style of your code will be checked with **pylint** and up to 10 points will be docked from your grade.
- Up to -70 points per usage of unapproved modules, built-in functions and constructs.
- -5 points per decent image that includes pixel values with decimal points. 0 credit for non-decent images.
- -5 points per function that does not have the function docstring in a proper format.
- Up to -30 points if you fail to create and use at least three functions that take arguments and return values.
- Up to -30 points if you fail to write and submit at least three tests for each of the three or more functions that take arguments and return values. You may write the tests using the unittest or the doctest modules.
- Up to -30 points for not reading the command-line arguments.
- -5 points for not handling an error (exception) that may occur when the program tries to open a file.
- -10 points for not using with to open a file, or not explicitly closing the opened file.
- A program that crashes with any kind of errors other than the error due to opening a non-existing file will receive 0 credit.

- **-20 points for using forbidden functions, modules, and constructs. You are also not allowed to include any methods in your classes other than __init__, __eq__, and __repr__, and the same penalty will be applied if you do.**