Homework #5: **threads** (150 pts)
Submit a compressed (.tgz) file with **source code** and **Makefile**

- Your job is to implement a *multi-threaded* (parallel) image-processing program that can *transform* ANY valid **ASCII ppm image** in one of *seven* ways (depending on user input).
  - **–I** := invert pixels
  - **–R** := rotate pixels 90° right
  - **–L** := rotate pixels 90° left
  - **–red** := keep red pixels only
  - **–green** := keep green pixels only
  - **–blue** := keep blue pixels only
  - **–C P** := adjust contrast by **P** percent

- The program will be invoked with the following **usage**:
  `UNIX> usage: ./a.out num_threads option [arg]`
  - **num_threads** := positive number of threads
  - **option** := -I , -R , -L , -red , -green, -blue, or -C
  - **arg** := decimal between 0 and 1 to specify **contrast**

- The program will read a **ppm** file on *stdin*
- The program will write the *converted* **ppm** file to *stdout*
- Your program must work with *any* **valid ASCII ppm** file
- Your program must be written in **C** (no **C++)**
- You cannot use the **system()** function
- **PPM** images have the following specifications:
  - First line contains "**P3**"
  - Second line contains two integers: **width** and **height**
  - Third line contains one integer: **maximum pixel value** (*maxValue*)
  - The remainder of the file contains **red**, **green**, **blue** values for each of the **width*height** *pixels*
  - All values are separated by white-space

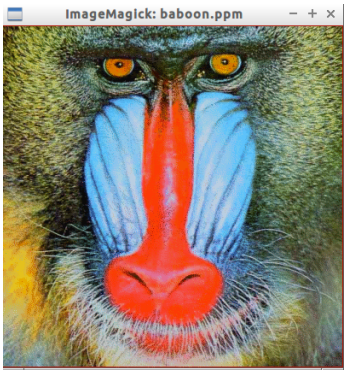
  E.g., 400 x 400 pixel ASCII ppm image of a baboon face

```
UNIX> head –n 4 baboon.ppm
P3
400 400
255
177 6 4
```

- Your program will use threads to do *parallel image processing* of the **ppm** file.
  - The image processing will be divided evenly amongst the **num_threads** threads
    - E.g., if **num_threads** = N, your program will spawn N threads:
      - thread 1 will process the *first* $(1/N)^{th}$ of the image
      - thread 2 will process the *second* $(1/N)^{th}$ of the image
      - …
      - thread N will process the *final* $(1/N)^{th}$ of the image

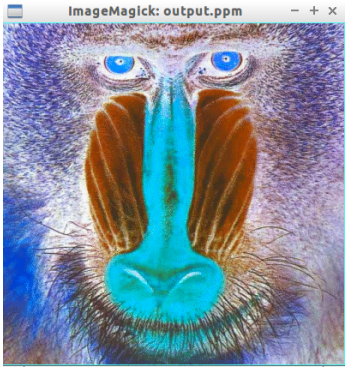
- Examples
  - You may need to install **ImageMagick** to use the *display* command
    - **`UNIX> sudo apt-get install imagemagick`**
    - (enter password)

```
UNIX> display baboon.ppm
```



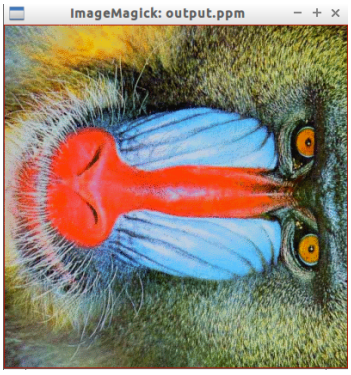
//use 4 threads to invert pixels; display

```
UNIX> ./hw4 4 –I < baboon.ppm > output.ppm
UNIX> display output.ppm
```



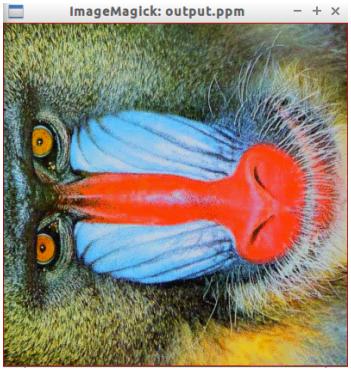
//use 4 threads to rotate pixels 90° right; display

```
UNIX> ./hw4 4 -R < baboon.ppm > output.ppm
UNIX> display output.ppm
```



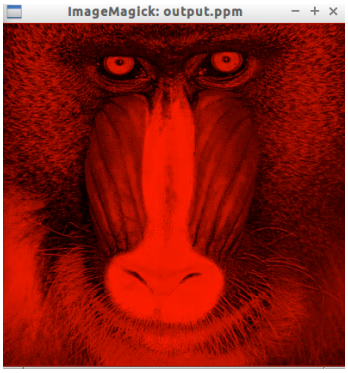
//use 4 threads to rotate pixels 90° left; display

```
UNIX> ./hw4 4 -L < baboon.ppm > output.ppm
UNIX> display output.ppm
```



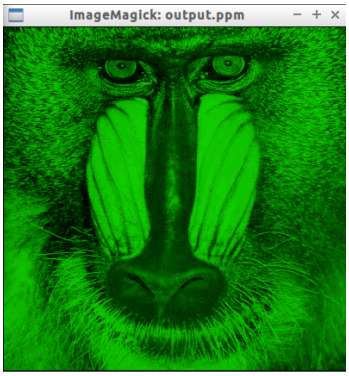
//use 4 threads to extract red content only; display

```
UNIX> ./hw4 4 -red < baboon.ppm > output.ppm
UNIX> display output.ppm
```



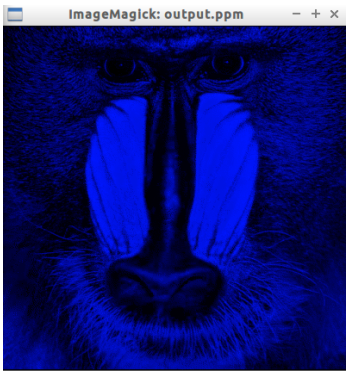
//use 4 threads to extract green pixels only; display

```
UNIX> ./hw4 4 -green < baboon.ppm > output.ppm
UNIX> display output.ppm
```



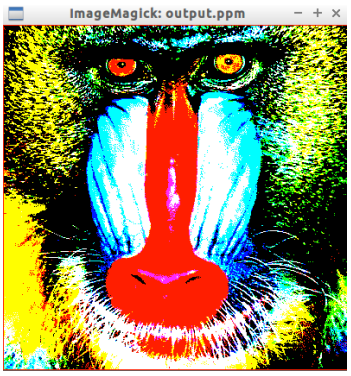
//use 4 threads to extract blue pixels only; display

```
UNIX> ./hw4 4 -blue < baboon.ppm > output.ppm
UNIX> display output.ppm
```



//use 4 threads to modify contrast by 80%

```
UNIX> ./hw4 4 –C 0.80 < baboon.ppm > output.ppm
UNIX> display output.ppm
```



// You can use pipes to connect multiple image transformations

```
UNIX> ./hw4 4 -R < baboon.ppm | ./hw4 4 -I | ./hw4 4 -C 0.98 > output.ppm
UNIX> display output.ppm
```

- Hints:
  - **–I** (invert) -> *pixel = maxValue – pixel*
  - **–red** -> zero-out *green* and *blue* pixels
  - **–C P** -> *if (pixel <= (maxValue / 2) pixel -= (maxValue*P)*
    *else pixel += (maxValue*P)*

  - **global variables** (shared between *threads*), e.g.,
    - *int ***pixels*

  - **malloc()** and **free()** for a 3D array of *pixels* (height × width × 3)

  - implement the **image transformations** *first*, then *refactor* to use N threads
    - *void* invert(void *arg);*

  - Is a mutex *really* needed?

  - test, test, test
    - Your code must work with ANY **valid ppm file** (of any size)

  - Draw pictures to help figure out *rotation*
    - On rotate right, where does pixel 0,0 end up?
    - On rotate left, where does pixel (height-1, width-1) end up?

  - use **ImageMagick** to convert *ANY* image file to **ASCII ppm**

    //convert an image from **.jpg** to **ASCII .ppm**
    `UNIX> ./convert –compress none image.jpg image.ppm`

    NOTE: the conversion may have comments (lines starting with #). Just delete such lines in the ppm file.