Digital Image Processing Functions: Reading and Point Operation

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***Abstract* – This is the basic image processing, which include read, enhance and resize function.**

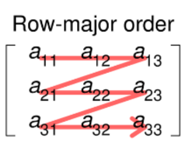
Index Terms - Image Processing

I. Introduction

This report is for Multi-model Image Processing class homework.

A. Assignment Requirement

1) *Image reading:* Give three raw-formatted images and 3 jpg images, please read the content correctly and display them on the screen, where the raw images are sized 512x512 in grayscale format. The pixel order is row-major as follows:



Also, please draw the centered 10x10 pixel values in each image in report.

2) *Image enhancement toolkit:* Give test six images, please implement log-transform, gamma-transform, and image negative, and compare them in report.
3) *Image downsampling and upsampling:* please implement bilinear and nearest-neighbor interpolation methods.

II. Helpful Hints

A. How to read image

1) *RAW format*

A RAW file has no header. Read the bytes directly into a buffer and interpret them with the agreed layout (e.g., 512×512, 8-bit, row-major). For 8-bit grayscale row-major, the offset is i*width + j..

2) *BMP format*

BMP image file include file header (14 bytes), image header (40 bytes), color palette (1024 bytes) and RAW file [1]. I will introduce each element below:

2.1) *BMP file header* (shown in Fig. 1): bfType is an identification code always be BM. Next, bfSize refers to the file size, which includes all the data. The bfReserved and bfOffBits fields can be filled with 0; this does not affect normal operation. The last bfOffBits value of 54 is fixed, which is 14 + 40. However, if you are using grayscale images, remember to add 1024 (to account for the color palette).

```
struct BmpFileHeader{
    uint16_t bfTybe = 0x424D;
    uint32_t bfSize;
    uint16_t bfReserved1 = 0;
    uint16_t bfReserved2 = 0;
    uint32_t bfOffBits = 54;
};
```

Fig. 1 BmpFileHeader format

2.2) *BMP Image Header* (shown as Fig. 2): biSize is size of the header (common is 40 bytes). Next, BiWidth and BiHeight separately represent image width and height. The biBitCount is the number of bits. For color images, set the RGB value to 8*3=24, and for grayscale images, set it to 8. And biClrUsed the number of colors in the palette for color images, set this to 0; for grayscale images with a custom palette, set this to 256. The last PelsPerMeter means density value can be 0 because most software seems to set this to 0 regardless of the dpi.

```
struct BmpInfoHeader{
    uint32_t biSize = 40;
    uint32_t biWidth;
    uint32_t biHeight;
    uint16_t biPlanes = 1; // 1=default, 0=custom
    uint16_t biBitCount;
    uint32_t biCompression = 0;
    uint32_t biSizeImage = 0;
    uint32_t biXPelsPerMeter = 0; // 72dpi=2835, 96dpi=3780
    uint32_t biYPelsPerMeter = 0; // 120dpi=4724, 300dpi=11811
    uint32_t biClrUsed = 0;
    uint32_t biClrImportant = 0;
};
```

Fig. 2 BmpImageHeader format

2.3) *Color Palette*: This is optional and may not be present. If the image is RGB color, there's no need to leave it blank (e.g., 00); simply leaving it blank is the correct way to do it. If the image is grayscale, you'll need to add a color palette yourself. The color palette is quite simple: 00 00 00 00 ~ FF FF FF 00. This is because grayscale images only require a single byte, while an entire BMP image must be represented in RGB. Therefore, the color palette transforms the raw file you see, for example, 00 becomes 00 00 00 and FF becomes FF FF FF.

2.4) *RAW file*: The special thing is that the reading method starts from the lower left corner of the image and reads to the upper right. The data is in BGR reverse order and their rows are aligned to 4 bytes. If it's 24-bit and width=42, each row's raw bytes are 42*3=126, so rowSize=128 (add 2 bytes padding per row). The height stays 42; you just add per-row padding.

B. How to enhance image

1) *Log transform:* The logarithmic transform applies a log function to each pixel, expanding dark tones and compressing bright tones so that fine details in shadow regions become more visible (see Fig. 3). The mapping is

$$S = c * \ln(1 + r) \quad (1)$$

where r is the input intensity and c is a scale factor. For images *r ∈ [0,255]*, a common choice is

$$r = \frac{255}{\ln(1 + 255)}$$

2) *Gamma-transform:* Human vision is not linear with respect to luminance; we are more sensitive to relative changes in darker tones than in bright ones. The gamma transform compensates for this nonlinearity by remapping each pixel's intensity via

$$S = 255\left(\frac{r}{255}\right)^{\gamma} \quad (2)$$

where $r \in [0, 255]$ is the input intensity, $S \in [0, 255]$ is the output, and $\gamma > 0$ is the exponent controlling the curve. Values $\gamma < 1$ brighten shadows (expand dark tones), while $\gamma > 1$ darken highlights (compress bright tones), allowing contrast to be redistributed according to perceptual needs (see Fig. 3). In practice, the mapping is applied per channel (for color images), typically via a 256-entry lookup table for efficiency.

3) *Image Negative:* The negative transform inverts intensity to create a tonal complement of the image. For each pixel is remapped by

$$S = 255 - r \quad (3)$$

where $r \in [0,255]$ is the input intensity and sss the output. This operation reverses contrast—dark regions become bright and vice versa—while preserving the dynamic range (see Fig. 3). It is useful for highlighting low-intensity details (e.g., in medical or astronomical images) and for visual inspection of structures obscured by bright backgrounds. For color images, the mapping is applied per channel (R, G, B), producing the chromatic negative of the original.

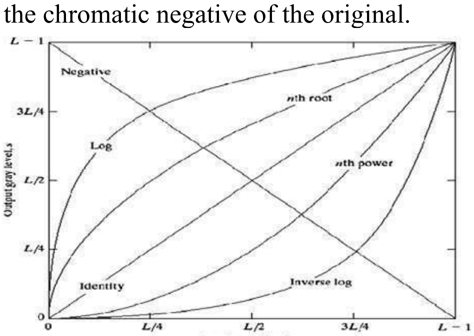


Fig. 3 Basic intensity transforms. The negative (descending line) inverts contrast. The log curve expands dark tones and compresses bright tones. Gamma curves appear as the "nth root" family (γ <1, brightening) and the "nth power" family (γ >1, darkening).

C. Image downsampling and upsampling

1) *Nearest neighbor (NN) Interpolation:* For each output pixel center (x,y), map back to the input coordinate space and copy the nearest input pixel's value(no averaging). This creates blocky replicas of input pixels when scaling up[2] (see Fig. 4).

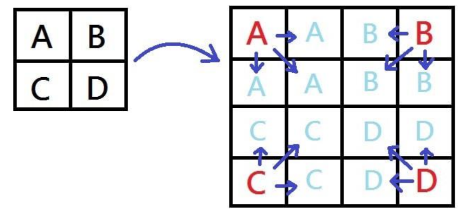


Fig. 4 Nearest-neighbor (NN) upsampling: each output pixel copies the value of the nearest input pixel, yielding block-like replication of the original cells (A–D).

2) *Bilinear Interpolation:* This method estimates the value at a non-integer location (x,y) by linearly interpolating twice: first along x on the rows above and below the target, then along y between those two results. It uses the four neighbors

$$(x_0, y_0), (x_1, y_0), (x_0, y_1), (x_1, y_1),$$
$$where\ x0 \le x \le x1\ and\ y0 \le y \le y1.\ \text{(see Fig. 5)}$$

$$F(x, y_0) = \frac{x_1 - x}{x_1 - x_0} F(x_0, y_0) + \frac{x - x_0}{x_1 - x_0} F(x_1, y_0) (4)$$

$$F(x, y_1) = \frac{x_1 - x}{x_1 - x_0} F(x_0, y_1) + \frac{x - x_0}{x_1 - x_0} F(x_1, y_1) (5)$$

Combining along y gives the bilinear estimate:

$$F(x, y) = \frac{y_1 - y}{y_1 - y_0} F(x_0, y_1) + \frac{y - y_0}{y_1 - y_0} F(x_1, y_1) (6)$$

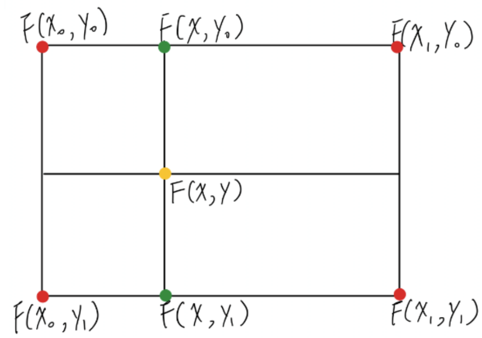


Fig. 5 Bilinear interpolation: the value at F(x,y) (yellow) is a convex combination of its four neighbors (red/green) via linear interpolation along x and then along y.

D. Pixel Centered

In most image libraries the origin is placed at the upper-left corner of the image domain, but when you "access a pixel at (i, j)" you're reading the value at the center of the pixel whose upper-left corner is (i, j). That subtle offset doesn't matter for many operations, but it does matter when rescaling. If you downsample a 5×5 image to 3×3 and naively map output corners with $x' = x \cdot \frac{W_{in}}{W_{out}}$,the first row maps as (0,0)→(0,0), (1,0)→(5/3,0), (2,0)→(10/3,0) (see Fig. 6): this is corner-based and introduces a half-pixel bias.

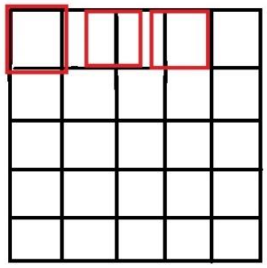


Fig. 6 Misaligned image. The first sample lands exactly on the top-left corner, the next near a grid line, etc. This introduces a half-pixel bias (everything is shifted toward the top-left), makes integer scales misalign, and can cause dark/light borders or asymmetry when resampling.

The standard fix is pixel-centered mapping: map centers with :

$$f(x) = (x + 0.5)\frac{W_{in}}{W_{out}} - 0.5 \quad (7)$$

$$f(y) = (y + 0.5)\frac{W_{in}}{W_{out}} - 0.5 \quad (8)$$

so the first row centers land at x≈0.33,2.0,3.67. Using the centered formula (7) and (8) aligns pixel centers between input and output, reducing alignment errors and producing the expected results for nearest/bilinear interpolation[3]. (Fig. 7)

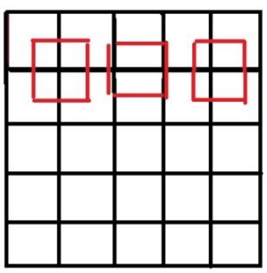


Fig. 7 Biased image. The output sample positions fall at the centers of the appropriate input cells. This keeps input/output grids aligned, preserves symmetry, and gives the expected behavior

III. RESULT

A. *Image reading:* Below is the result of read image (Fig. 8-13), and just see the centered 10x10 pixels values of image which is useful for quick verification, also I have already use python library quickly to check it is correct or not.

```
---- Center 10x10: original (512x512, c=3)
 152 151 154 167 155 142 139 136 139 143
 150 175 177 178 180 177 174 173 153 130
 149 165 155 155 170 174 173 171 163 159
 149 158 169 171 172 166 151 165 156 138
 164 170 177 177 180 177 172 178 170 156
 172 186 185 175 177 181 184 180 176 165
 184 183 166 168 173 170 167 176 171 171
 181 170 175 190 190 188 178 176 175 171
 183 187 186 190 189 188 176 162 158 153
 190 192 184 176 188 186 184 174 164 159
------------------------------------------
```

Fig. 8 Baboon.bmp 10x10 center pixels

```
---- Center 10x10: original (512x512, c=3)
  88  74 105 105  48  57  62  75 140 142
  83  71  85 101  58  50  63  65 129 143
  84  70  65  67  53  49  54  66 123 141
  82  66  56  53  45  53  55  69 127 136
  86  65  60  49  47  52  55  67 118 138
  79  71  59  50  51  50  55  72 122 133
  86  76  61  53  54  54  58  68 117 132
  89  77  61  59  52  56  55  65 116 132
  84  78  61  57  55  57  58  65 117 137
  78  77  55  58  52  56  57  68 127 136
------------------------------------------
```

Fig. 9 Boat.bmp 10x10 center pixels

```
---- Center 10x10: original (512x512, c=3)
 105 110 108 111 118 130 126 123 115 107
 106 109 109 114 123 131 124 117 116 107
 111 107 111 120 129 127 124 115 115 101
 110 107 116 118 123 126 119 111 113 108
 106 109 109 114 112 113 108 109 114 108
  99 101 102 103 104 108 109 108 109 109
 101 102  95 100 104 106 106 106 107 108
  94  96 102 105 108 101 102 104 108 107
  94  99 104 104 103 101 103  98 106 108
 101 101 101  99 104  99 104 101 104 104
------------------------------------------
```

Fig. 10 F16.bmp 10x10 center pixels

```
---- Center 10x10: original (512x512, c=1)
  56  60  69  64  54  74  80  78  78 121
  47  59  62  69  54  62  48  50  52  70
  70  74  73  69  51  58  44  46  46  57
  85  85  87  72  45  59  45  45  55  68
  65  81  80  78  49  64  52  54  65  69
  60  63  78  80  53  83  59  63  78  62
  59  66  69  66  57  72  66  71  74  51
  53  64  63  75  54  67  68  59  57  53
  57  64  63  69  66  74  75  68  89 101
  77  68  74  76  94  96  99  88 106 103
------------------------------------------
```

Fig. 11 goldhill.raw 10x10 center pixels

```
---- Center 10x10: original (512x512, c=1)
 195 195 195 192 169 135 133 137 138 148
 196 196 189 157 124 128 135 144 145 145
 196 187 149 123 127 131 135 142 142 137
 180 135 116 117 124 130 131 132 137 133
 124 102 115 116 120 126 124 120 114 111
 100 102 114 114 114 118 120 117 112  92
 101 100 113 106  98  89  90 104 101  84
 105  96  99  94  92  78  75  79  83  76
  92  90  90  84  79  75  71  73  72  71
  85  79  76  77  76  71  73  73  69  77
------------------------------------------
```

Fig. 12 lena.raw 10x10 center pixels

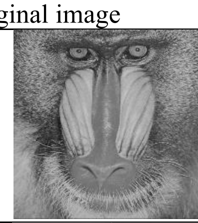
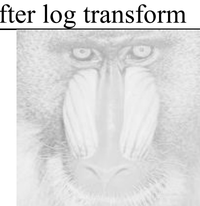
```
---- Center 10x10: original (512x512, c=1)
  63  43  45  60  71  61  58  25   4  20
  66  50  46  42  55  40  52  34   4  26
  60  57  35  36  47  32  48  25  15  56
  86  57  33  37  23  34  25  35  66  59
 112  91  57  27  27  14  27  49  57  46
 108  69  69  39  20   9  42  73  52  46
 113  92  45  32  13  44  55  65  55  32
 131  90  59  27  33  62  72  62  59  47
 144  96  40  30  57  92  73  66  60  45
 133  72  34  61  99 112 100  97  80  48
------------------------------------------
```

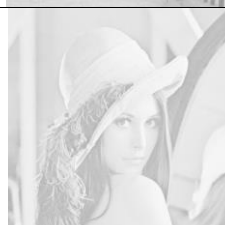
Fig. 13 peppers.raw 10x10 center pixels

B. *Image enhancement toolkit:* After reading image, I use log-transform, gamma-transform, and image negative, (HELPFUL HINTS B part) to enhance each image, and I will compare them.

1) *Log transform*

TABLE I
LOG TRANSFORM FOR EACH IMAGE

Original image	After log transform
	
	

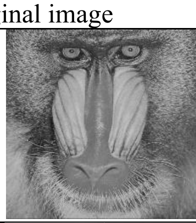
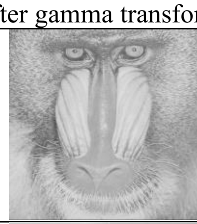
	
	
	
	

From Table I, the dark regions become noticeably clearer than in the original image. Overall contrast is enhanced while preserving natural appearance.

2) *Gamma-transform*

TABLE II

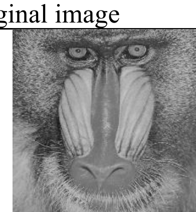
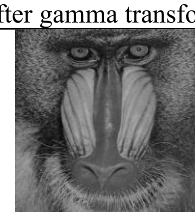
GAMMA TRANSFORM FOR EACH IMAGE ($\gamma < 1$)

Original image	After gamma transform
	
	
	
	
	
	

As shown in Table II, $\gamma = 0.5$ substantially clarifies dark regions relative to the original and improves overall contrast without introducing visible artifacts.

TABLE III

GAMMA TRANSFORM FOR EACH IMAGE ($\gamma > 1$)

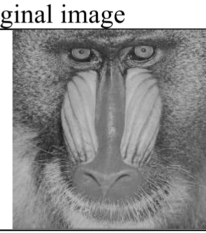
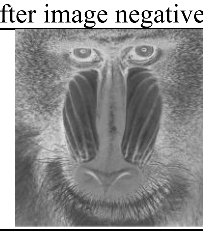
Original image	After gamma transform
	
	

Relative to Table II, which uses γ=0.5 to reveal shadow detail and boost perceived contrast, Table III applies γ>1 to suppress overly bright regions—darkening highlights and compressing bright tones—thereby reducing glare without altering spatial detail.

3) *Image Negative*

TABLE IV

IMAGE NEGATIVE FOR EACH IMAGE

Original image	After image negative
	

Based on Table IV, the negative transform inverts luminance: bright regions become dark, and vice versa, while edges and structures are preserved.

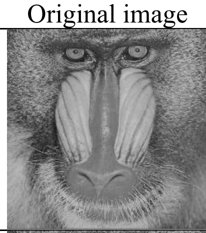
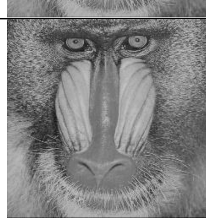
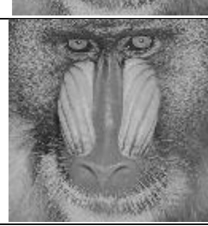
C. *Image downsampling and upsampling*

In this section, I use baboon.bmp as an example to compare results at different image sizes.

1) original image (512x512) -> (128x128)

TABLE V

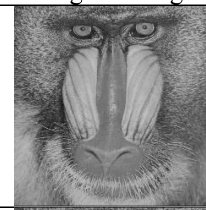
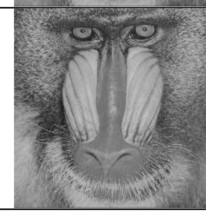
IMAGE DOWNSAMPLING FOR IMAGE

	Original image	Resized image
nearest		
bilinear		

2) original image (512x512) -> (32x32)

TABLE VI

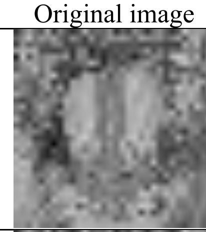
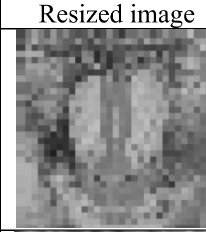
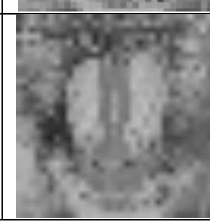
IMAGE DOWNSAMPLING FOR IMAGE

	Original image	Resized image
nearest		
bilinear		

3) original image (32x32) -> (512x512)

TABLE VII

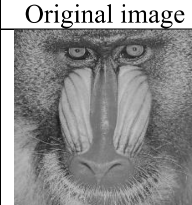
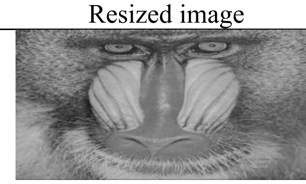
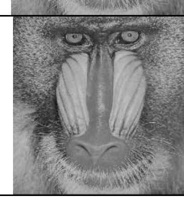
IMAGE UPSAMPLING FOR IMAGE

	Original image	Resized image
nearest		
bilinear		

4) original image (512x512) -> (1024x512)

TABLE VII

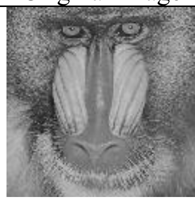
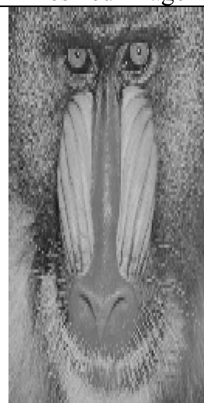
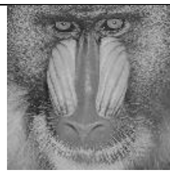
IMAGE UPSAMPLING FOR IMAGE

	Original image	Resized image
nearest		
bilinear		

5) original image (128x128) -> (256x512

TABLE VIII

IMAGE UPSAMPLING FOR IMAGE

	Original image	Resized image
nearest		
bilinear		

Comparing nearest-neighbor (NN) and bilinear interpolation across Tables V–VIII shows that bilinear generally preserves structure and visual smoothness better than NN. For example, in Table VI (baboon's eye region), NN produces blocky, more blurred edges, whereas bilinear retains finer contours. In Table VII, bilinear yields smoother tonal transitions than NN, which exhibits stair-step artifacts. Overall, bilinear delivers better perceptual quality than nearest neighbor in these examples.

IV. DIFFICULTIES I MET

I originally thought this was a quick project, but I realized I didn't fully grasp the underlying principles. This time, I spent a lot of time figuring out how to implement it. However, due to time constraints, I made some changes based on the AI-powered code. During the implementation process, I discovered that Windows doesn't support reading raw files, so I implemented the output as a bmp file. I also wanted to implement an interface, but the time allowed was too short, so I'll have to wait and see if I have time to make up for it. I hope I can set aside more time next time to complete the project.

REFERENCES

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