1.1

a) R:5.75 or 5 or 6 G:4.5 or 4 or 5 (4 pts.)
b) B: 8 R:7.5 or 7 or 8 (4 pts.)
   if you compute pixel values at wrong location with correct formulas, you can only get 2 pts.

1.2

A-2 (2 pts.) high contrast / histogram equaliztion / some regions become daker or brigher comparing with original image (2 pts.)
B-4 (2 pts.) a lot dark regions (2 pts.)
C-1(2 pts.) a lot bright regions (2 pts.)
D-3 (2 pts.) reverse mapping (2 pts.)
We don't accept the justification like: it is the only one left…
If you make a wrong matching, then the maximum point you might get for justification is 1 pt.
We don't give .5 pt for this problem.

2.

a.

Uniform denoised image:

5	4	4
4	4	3
5	5	4

Gaussian denoised image:

4	4	4
4	4	4
5	5	4

PSNR:

Uniform: $57.7 - 10\log_{10}(50)$ or 40.68

Gaussian: $57.7 - 10\log_{10}(46)$ or 41.05

Discussion:

Gaussian denoising give better performance since it considers the geometric closeness between neighboring pixels and assign the weights accordingly.

b.

Median filter denoised image:

4	4	5
4	3	3
5	5	5

PSNR: $57.7 - 10\log_{10}(72)$

Yes. Bilateral filter applied Gaussian filter not only according to the pixel's geometric closeness, it also considers the closeness between the pixel values. Thus, it is good at preserving edges.

3.

a) Short questions. Answer the following questions with NO MORE THAN 3 WORDS. (4 points, 2 for each question)

   a. Name the classifier used in Structured Edge. Random Forest/Structured random forest/structured forest

   b. How did Canny obtain thin edges? Non-maxima suppression

b) Long questions. (21 points. 5 points for a), 3 for each of b)-e), 4 for f))

   a. What is the purpose of hysteresis thresholding in Canny edge detector? What are the two major (user-defined) parameters for hysteresis thresholding? Briefly explain the process.

Purpose: To determine which edges are really edges and what are not.
Parameters: High and low thresholds
Process:

Edges with gradient maginitude greater than *HighThreshold* are sure to be edges; (1pt)

those below *LowThreshold* are sure to be non-edges, which are discarded. (1pt)

Other edges: check their connectivity. If connected to "sure-to-be-edge" pixels → part of edges, else discarded. (1pt)

(1 pt for purpose, 1 pt for parameters, 3 pts for process)

   b. The following three edge maps are generated using the Canny edge detector. They differ in the value of σ (standard deviation) used. Rank the three output images based on σ from high to low.

Answer: (a) (c) (b), marks given only if the answers are completely correct.

(a) Sigma sqrt(32), (c) sqrt(8), (b) sqrt(2)

   c. How is Structured Edge different from traditional edge detectors like Sobel, LOG and Canny?

SE is a machine-learning based/ data-driven approach, while traditional methods mainly use some methods to compute the gradient.

   d. What are the major steps of Sobel edge detector?

      i. Compute Horizontal gradient, compute vertical gradient
      ii. Compute magnitude of gradient
      iii. Thresholding

e. Suggest one way to improve one of the drawbacks of Sobel edge detector? Include the drawback that you are dealing with in your answer.
    i. Add Gaussian filtering, to remove noise
    ii. Non-maximum suppression, for thinning edges
    iii. Any other answer that makes sense

f. Compute the gradient at the <u>central</u> pixel using the Sobel gradient operator (the one in **bold** font). Compute the magnitude of gradient (you can keep the square root symbol in your final answer).

11	19	7	1	22
2	2	4	4	23
7	8	**6**	11	7
5	10	12	10	10
27	12	20	17	12

Answer:

X direction: (4-2)+(11*2-8*2)+(10-10)=8 (1.5pt)

Y direction: (10-2)+(12*2-4*2)+(10-4)=30 (1.5pt)

Magnitude: Sqrt(964)= 31.0483 (1pt)

Problem 4: Digital Halftoning (25 pts.)
4.1 Halftonig Basics (10 pts.)
a) For grayscale digital halftoning, we applied 5 halftoning algorithms to Fig 4.1
1) Binarization with a fixed threshold
2) Binarization with random threshold
3) Dithering with Bayer's matrix I_2
4) Dithering with Bayer's matrix I_{16}
5) Floyd-Steinberg error diffusion

The obtained 5 results are presented below (next page). Please match the specific digital halftoning method (denoted by #1, #2, #3, #4 and #5) to the output images (denoted by A, B, C, D, and E), and justify your answer. (5 pts.)
A - #4 (0.5') Lots of block patterns→dithering. It is done by I2 due to the low resolution (less details). (0.5')
B - #1 (0.5') <u>Large regions</u> with monotonous colors. (0.5')
C - #2 (0.5') Binarization with random threshold introduces random noise. (0.5')
D - #3 (0.5') Lots of block patterns→dithering. It is done by I16 because it has more details than A. (0.5')
E - #5 (0.5') Typical FS error diffusion result. It has zig-zag maze-like artifacts. (0.5')

b) What's the difference and relationship between RGB and CMY color space? How can one display the Yellow color in the computer screen? How can one print one Blue dot on white paper? (5 pts.)

RGB color model, using red, green, and blue light, is a additive color space for monitor display. While CMY color model, using light-absorbing cyan, magenta, and yellow inks, is a subtractive color space for printing. The 2 systems are complementary, i.e. (R,G,B) = (1,1,1) – (C,M,Y). (3')

For Yellow in the screen, use RGB(255,255,0). (1')

For Blue on the white paper, use CMY(1,1,0). (1')

4.2 Dithering Implementation (16 pts.)

In this problem, you will perform dithering on Figure 4.2 using a certain dithering matrix

$$T = [240\ 144\ 176\ 64\ \ 208\ 48\ 0\ 112\ \ 96\ 32\ 16\ 192\ \ 80\ 160\ 224\ 128\ ]$$

Please show your half-toned output. Note: Thresholding is for the range [0, 255].

255	255	255	255	60	60	60	60
255	255	255	255	60	60	60	60
255	255	255	255	60	60	60	60
255	255	255	255	60	60	60	60
180	180	180	180	120	120	120	120
180	180	180	180	120	120	120	120
180	180	180	180	120	120	120	120
180	180	180	180	120	120	120	120

Figure 4.2 Dithering Input

a) Show the dithering results. (7 pts.)

255	255	255	255	0	0	0	255
255	255	255	255	0	0	255	0
255	255	255	255	0	255	0	0
255	255	255	255	255	0	0	0
0	255	0	255	0	0	0	255
255	255	255	255	0	255	255	255
255	255	255	255	255	255	255	0
255	0	0	255	255	0	0	0

b) Comment on the performance of dithering matrix T. Please state your reason. (3 pts.)

Dithering Matrix T cannot work well (1'). The output halftoning has diagonal artifacts due to the small elements in the matrix diagonal (top right to bottom left) and inner 2*2 submatrix. The matrix is not evenly distributed. (2')

c) Please design a better dithering matrix that has the same elements given in the above two threshold matrices. Please explain why yours is better. (3 pts.)

Just try to evenly distribute the numbers. Evenly distributed dithering matrix gives a uniform distributed global threshold results (0.5'). One example could be: (2.5')

$$T = [208\ 144\ 64\ 0\ \ 80\ 16\ 224\ 160\ \ 112\ 48\ 240\ 176\ \ 128\ 96\ 192\ 32\ \ ]$$

(Bayer's I4 loses 0.5' due to small elements in the top left – bottom right diagonal. Bayer's ditering is not a perfect halftoning method.)

d) Is PSNR a good metric to evaluate the quality of dithered images? Please justify your answer. (3 pts.)

No, it is not (1’). PSNR, which can easily be affected by high frequency information, is a metric pixel-wisely evaluates the difference of the 2 images. While the focus of halftoning is to render the output image visually similar to the initial image, utilizing the low pass filtering function of human eyes. There is no certain relation between PSNR values and halftoning performance. (2’)