1. [24%] Answer the following questions:

(a) What is the purpose of subband coding? How is it used in discrete wavelet transform of an image?

(b) Consider the periodic sequence "1 3 2 1 3 2 1 3 2 1 3 2 ..." down-sampled by a factor of 2. Use this as an example to explain the cause of "aliasing". How is this related to the sampling theorem?

(c) For JPEG coding, the quantization matrix ($Z(u,v)$) is a pre-specified normalization matrix multiplied by a positive constant. How is this constant related to the compression ratio and the quality of the reconstructed image?

(d) Explain what the "impulse response" of a frequency-domain filter is, and use it to explain the "ringing" caused by ideal LPF in images.

(e) The "degradation function" of an image is given as $g(x,y) = h(x,y) * f(x,y) + \eta(x,y)$. Here f and g represent the images before and after degradation, respectively. Explain what h and η represent.

(f) Explain the source of wrap-around error in discrete Fourier transform, and the standard procedure to prevent it.

2. [16%] These are questions related to the group presentations. Each is worth 2 points, up to a total of 16 points. Clearly indicate the questions you're answering.

(a) Give two applications of image inpainting.

(b) The active contour energy function involve internal and external energy terms. Which is intended to make the contour "fit to image edges"?

(c) What is the meaning of "saliency" in images?

(d) Name a type of convolutional neural networks used in image compression.

(e) Pairs of image patches are used to train models for learning based super resolution. What is the relation between the two images in a pair?

(f) Give two methods/techniques of obtaining depth information of images.

(g) Describe the least-significant-bits method of image watermarking.

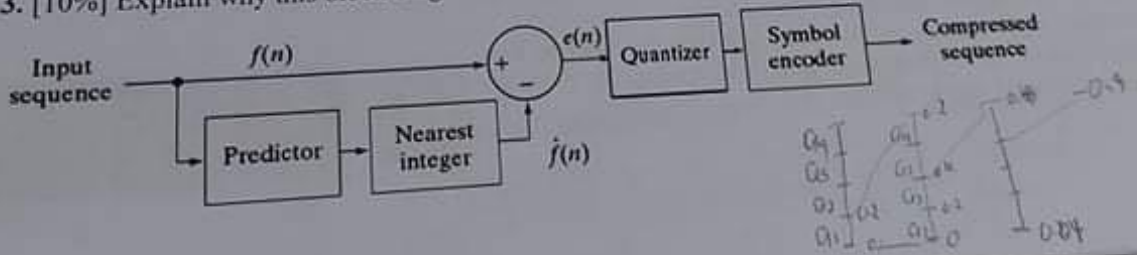
(h) One denoising method using CNN aims to learn a residual function. What does this function try to model?

(i) What information is used when grouping pixels into superpixels with the SLIC algorithm?

(j) What does the "blending" step in image stitching do?

(k) What differences are in the multiple images used to produce a HDR image?

3. [10%] Explain why this block diagram for a lossy predictive coder is incorrect, and how you can fix it.



4. [10%] This problem is about arithmetic coding. Given the intervals for the four symbols a_1, a_2, a_3, a_4,

(a) Give the 3-element string obtained by decoding 0.25.

(b) Find the shortest binary number needed to encode the 2-element string a_2a_3.

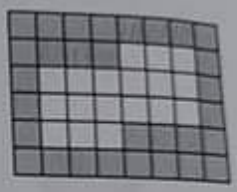
Source Symbol	Probability	Initial Subinterval
a_1	0.2	[0.0, 0.2)
a_2	0.2	[0.2, 0.4)
a_3	0.4	[0.4, 0.8)
a_4	0.2	[0.8, 1.0)

5. [10%] This is about 2-D DFT using the provided images. Assume that the original size is 100x100.

(a) Among the right four images, which is the likely Fourier transform of the leftmost image? Explain.
(b) The transform images have the brightest part near the center. How do we achieve this centering?
(c) What happens if the two rectangles in the original image are rotated clockwise by 10 degree?
(d) What happens if the two rectangles are moved downward by 30 pixels?
(e) What happens if the original image is resampled to 200x200 while keeping the appearance unchanged?

6. [10%]

(a) In the binary image, the white pixels are the foreground pixels. Using a structuring element consisting of the center pixel and its 4 neighbors, draw the foreground pixels after the morphological operation given below. Here set A contains the foreground pixels and set B is the structuring element. The operation $\oplus$ is dilation.



$$(A \oplus B) - A$$

(b) Give the two structuring elements needed for using hit-or-miss transform to detect the shape represented by B in (a).

7. [12%] For the following sequence of pixel values: 1 2 3 4 5 6 7 8 7 6 5 4 3 2 1 0

(a) Compute the entropy of the sequence itself.
(b) Create the "difference sequence" by replacing every pixel value (except for the first one) with its difference from the previous pixel value.
(c) Compute the entropy of the difference sequence.
(d) Use the above results to explain the benefit of predictive coding in image compression.

The equation for entropy is given by $H = -\sum_f p(f)\log_2[p(f)]$. Here $p(f)$ is its probability of a symbol f.

8. [8%] The transfer function of a filter is given by $H(u,v) = \dfrac{[D(u,v)]^2}{D_0^2 + [D(u,v)]^2}$.

(a) Draw its H-vs-D plot, indicating where D_0 is.
(b) The three right images are results of applying the filter to the leftmost image. Order them according to increasing D_0. Provide an explanation of your ordering.