

ECE 5273

Test 2

Friday, May 14, 2021
10:30 AM - 12:30 PM

Spring 2021

Name: SOLUTION

Dr. Havlicek

Student Num: _____

Directions: This is an open notes test. You may use a clean copy of the course notes as published on the course web site and a calculator. Other materials are not allowed. You have 120 minutes to complete the test. All work must be your own. You may work the test on this test paper or you may use your own blank paper. Upload a scan or photograph of your test paper to the course Canvas page no later than 12:45 PM on Friday, May 14, 2021.

SHOW ALL OF YOUR WORK for maximum partial credit!

GOOD LUCK!

SCORE:

1. (20) _____

2. (20) _____

3. (20) _____

4. (20) _____

5. (20) _____

TOTAL (100):

On my honor, I affirm that I have neither given nor received inappropriate aid in the completion of this test.

Name: _____

Date: _____

1. 20 pts. True or False. Mark *True* only if the statement is **always** true.

TRUE FALSE

X _____ (a) 3 pts. DOG filters are very useful in human visual modeling. Notes p. 5.98

_____ X (b) 3 pts. Any grayscale morphological filter can be implemented by pointwise multiplication of DFT's if sufficient zero padding is applied. Morphological filters are nonlinear

X _____ (c) 3 pts. Linear filtering can be implemented by pointwise multiplication of DFT's if sufficient zero padding is applied. Notes p. 5.33

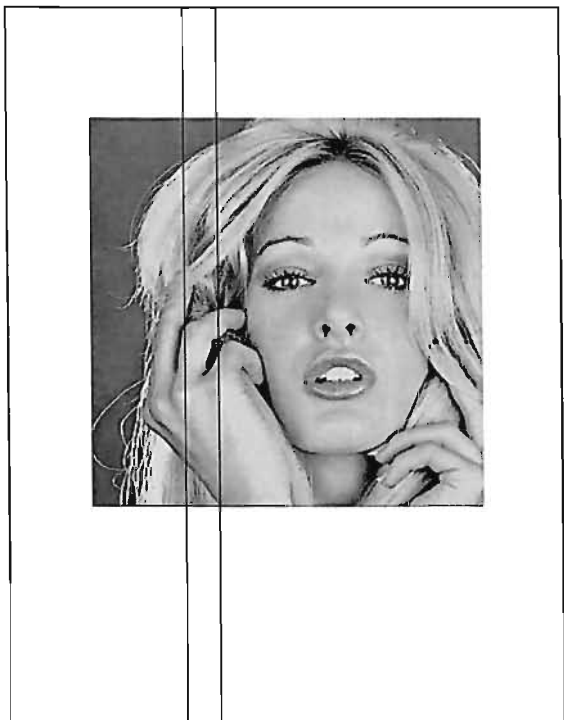
X _____ (d) 3 pts. In grayscale template matching, the normalized cross-correlation $\hat{C}_{B_T \circ I(i,j), T}$ always takes a value between 0 and 1 (inclusive). Notes p. 8.42

X _____ (e) 3 pts. One of the main features of Canny's Edge Detector is that it computes a second derivative in the direction normal to the edge. Notes p. 8.87

X _____ (f) 3 pts. In anisotropic diffusion, the diffusion coefficients control the inhibition of smoothing over edges and encourage smoothing in non-edge image regions. Notes p. 8.94

OH MY! _____ (g) 2 pts. The Salesman used to be an ECE professor at OU, but he got thrown out for saying that Trump incited the Capitol insurrection.

2. **20 pts.** The ECE department photocopier has developed a problem. There are vertical black lines on all of the copies. The lines are always one pixel wide and are always separated by at least 64 columns. Because it is a hardware problem, these same vertical black lines show up when the photocopier is used to make scans as well. Two examples are given below:



ECE 5273
Test 2
Thursday, May 8, 2013
10:30 AM - 12:30 PM

Spring 2013 Name: _____
Dr. Bucklew Student Num: _____

Directions: This is an open notes test. You may use a clean copy of the course notes as published on the course website. Other materials are not allowed. You have 120 minutes to complete the test. All work must be your own.

SHOW ALL OF YOUR WORK for maximum partial credit!

GOOD LUCK!

SCORE

1. (25) _____

2. (25) _____

3. (25) _____

4. (25) _____

TOTAL (100) _____

On my honor, I affirm that I have neither given nor received inappropriate aid in the completion of this test.

Name: _____ Date: _____

Unfortunately, it will be at least three weeks before a technician can come out to repair the problem. In the meantime, here is the plan: instead of copying, everybody will use the photocopier to scan instead. A nonlinear digital gray scale filter will then be applied to remove the vertical black lines from the scanned images, which can then be printed.

Because of your excellent performance in ECE 5273, you have been asked to design the filter. Carefully explain which filtering operation you recommend, which window or structuring element, and the reasons for your choices.

Work Space for Problem 2...

- The window should be as small as possible to avoid making undesirable changes to good pixels.
- Since the bad lines are always vertical, always one pixel wide, and always separated by at least 64 columns, the window should be a ROW.
 - ROW(3) is the smallest window that will work.
- As can be seen in the example images, the bad black lines will generally cross both dark and light structure in the image. MEDIAN will replace the bad pixels with a value that is similar to the majority of the pixels in the neighborhood and it will not blur edges.

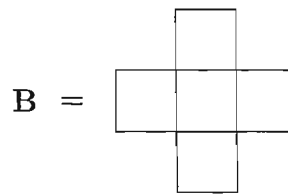
⇒ USE MEDIAN with window B = ROW(3)

CLOSE would also work, but it is not as good as MEDIAN because it involves two primitive filtering operations... so the effective spatial extent is larger [ROW(5)] and it would make more changes to the good pixels.

3. 20 pts. The 5×5 image I shown below has 3-bit pixels in the range $0 \leq I(m,n) \leq 7$:

$$I = \begin{bmatrix} 4 & 7 & 2 & 5 & 3 \\ 1 & 5 & 4 & 7 & 4 \\ 0 & 5 & \mathbf{7} & 2 & 3 \\ 3 & 7 & 1 & 2 & 4 \\ 2 & 4 & 4 & 4 & 5 \end{bmatrix}$$

A grayscale morphological EROSION is to be performed using the structuring element $B = \text{CROSS}(5)$ shown here:

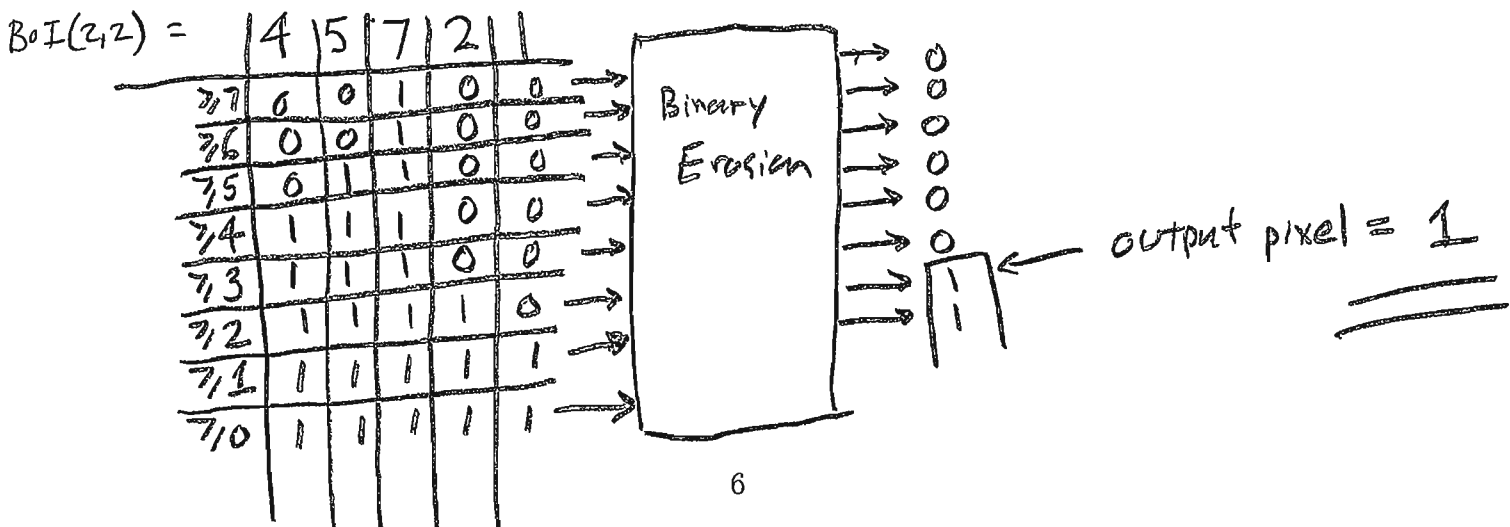


Implement the EROSION filter as a **stack filter** to compute the filtered output value for the middle pixel $I(2,2)$ shown above as a large boldface "7."

Note: you do **not** have to apply the filter at any other pixels! Just apply it at the middle pixel $I(2,2)$ *only* to find the filtered output value for that pixel *only*.

Hint: extract the window set $B \circ I(2,2)$ and arrange it as a horizontal 1D array. Then compute the binary threshold decomposition for the window set and apply a binary EROSION filter to each binary threshold signal. Finally, combine the results using the stacking property to get the final gray scale value for the filtered pixel.

More workspace is provided on the following page in case you need it.



4. 20 pts. Pixels in the 6×6 image I shown below take values in the range $\{0, 1, 2, \dots, 99\}$. The image is sent through a communication channel where it is corrupted by additive noise. The received image J is also shown below.

$$I = \begin{bmatrix} 11 & 11 & 12 & 12 & 13 & 13 \\ 11 & 0 & 12 & 13 & 13 & 13 \\ 12 & 12 & 13 & 13 & 13 & 14 \\ 12 & 13 & 13 & 13 & 14 & 14 \\ 13 & 13 & 13 & 14 & 0 & 14 \\ 13 & 13 & 13 & 14 & 14 & 14 \end{bmatrix}$$

$$J = \begin{bmatrix} 11 & 11 & 12 & 12 & 13 & 13 \\ 11 & 11 & 12 & 13 & 99 & 13 \\ 12 & 12 & 13 & 13 & 13 & 14 \\ 12 & 13 & 13 & 13 & 14 & 14 \\ 99 & 99 & 13 & 14 & 0 & 14 \\ 13 & 13 & 99 & 99 & 14 & 14 \end{bmatrix}$$

Design a nonlinear filter to restore the received image by attenuating the noise. Handle edge effects by replication. Explain your solution. Show the restored image K below and compute the ISNR. There is workspace on the following page.

The noise introduces positive spikes that need to be removed. But the image contains negative spikes that need to be retained, so we need to use an asymmetric smoother that attenuates positive spikes only. To minimize distortion, we need to use a small 2D window.

\Rightarrow USE OPEN with $B = \text{CROSS}(5)$

Show the restored image here.

$$K = \begin{bmatrix} 11 & 11 & 12 & 12 & 13 & 13 \\ 11 & 0 & 12 & 13 & 13 & 13 \\ 12 & 12 & 13 & 13 & 13 & 14 \\ 12 & 13 & 13 & 13 & 14 & 14 \\ 13 & 13 & 13 & 14 & 0 & 14 \\ 13 & 13 & 14 & 14 & 14 & 14 \end{bmatrix}$$

$$\text{ISNR} = 45.68 \text{ dB}$$

More Workspace for Problem 4.

ERODE

	11	0	11	12	12	13	
11	11	0	11	12	12	13	13
0	0	0	0	12	13	13	13
11	11	0	12	13	13	13	13
12	12	12	13	13	0	14	14
12	12	13	13	0	0	0	0
13	13	13	14	0	14		14
	13	13	13	14	0	14	

DILATE

(K)

11	11	12	12	13	13
11	0	12	13	13	13
12	12	13	13	13	14
12	13	13	13	14	14
13	13	13	14	0	14
13	13	14	14	14	14

|K-I|

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0

|J-I|

0	0	0	0	0	0
0	0	0	0	86	0
0	0	0	0	0	0
0	0	0	0	0	0
86	86	0	0	0	0
0	86	86	0	0	0

$$MSE(K) = \frac{\sum_{i=0}^5 \sum_{j=0}^5 [K(i,j) - I(i,j)]^2}{36}$$

$$= \frac{1}{36}$$

$$MSE(J) = \frac{\sum_{i=0}^5 \sum_{j=0}^5 [J(i,j) - I(i,j)]^2}{36}$$

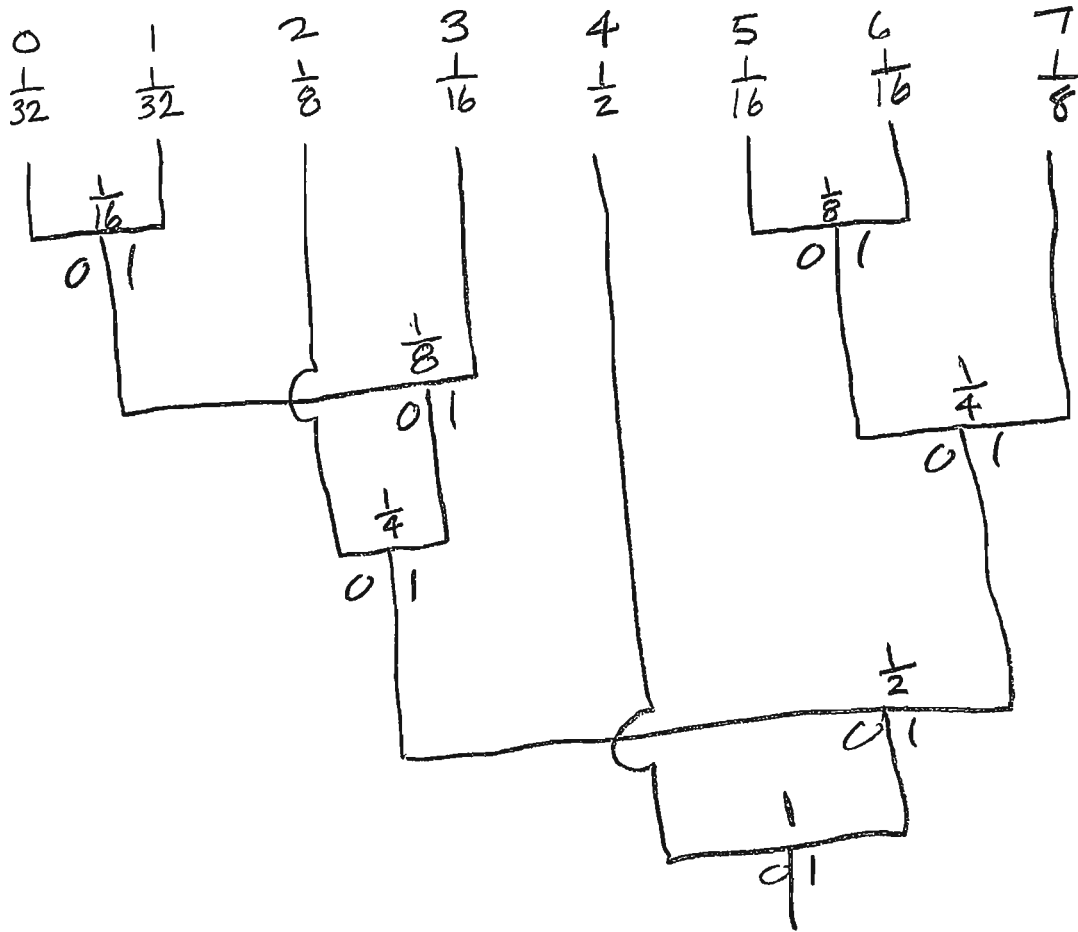
$$= \frac{5 \cdot (86)^2}{36} = \frac{36,980}{36}$$

$$ISNR = 10 \log_{10} \frac{MSE(J)}{MSE(K)} = 10 \log_{10} \frac{36,980}{1} = 45.67967 \text{ dB}$$

5. 20 pts. Gray scale digital images I with 3 bits per pixel and gray levels in the range $\{0, 1, \dots, 7\}$ are modeled as coming from an information source with the following source symbol probabilities (normalized histogram):

k	0	1	2	3	4	5	6	7
$p_I(k)$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{8}$

- (a) 12 pts. Design a Huffman code to encode these images.



k	0	1	2	3	4	5	6	7
\hat{k}_k	10100	10101	100	1011	0	1100	1101	111
$L(\hat{k}_k)$	5	5	3	4	1	4	4	3

Problem 5 cont..

- (b) 4 pts. Find the expected BPP (bits per pixel) and CR (compression ratio) for the coded images $C(I)$.

$$\begin{aligned} \text{Original BPP} &= 3 \\ \text{Coded BPP} &= 5 \cdot \frac{1}{32} + 5 \cdot \frac{1}{32} + 3 \cdot \frac{1}{8} + 4 \cdot \frac{1}{16} + 1 \cdot \frac{1}{2} + 4 \cdot \frac{1}{16} + 4 \cdot \frac{1}{16} + 3 \cdot \frac{1}{8} \\ &= \frac{5}{32} + \frac{5}{32} + \frac{3}{8} + \frac{4}{16} + \frac{1}{2} + \frac{4}{16} + \frac{4}{16} + \frac{3}{8} \\ &= \frac{5+5+12+8+16+8+8+12}{32} = \frac{74}{32} = \underline{\underline{2.3125}} \end{aligned}$$

$$\text{CR} = \frac{3}{2.3125} = \underline{\underline{1.2973}}$$

- (c) 4 pts. Does your code achieve the theoretical lower bound on BPP for the coded images? Explain why or why not.

YES - because the source symbol probabilities are all integer powers of 2.