ECE 5273
Test 2

Thursday, May 8, 2014
10:30 AM - 12:30 PM

Spring 2014 — 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. 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):

____

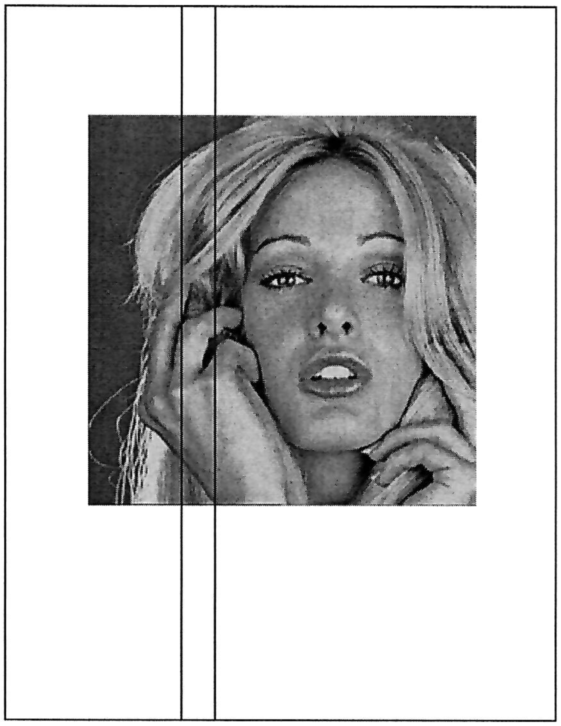
On my honor, I affirm that I have neither given nor received inappropriate aid in the completion of this test.

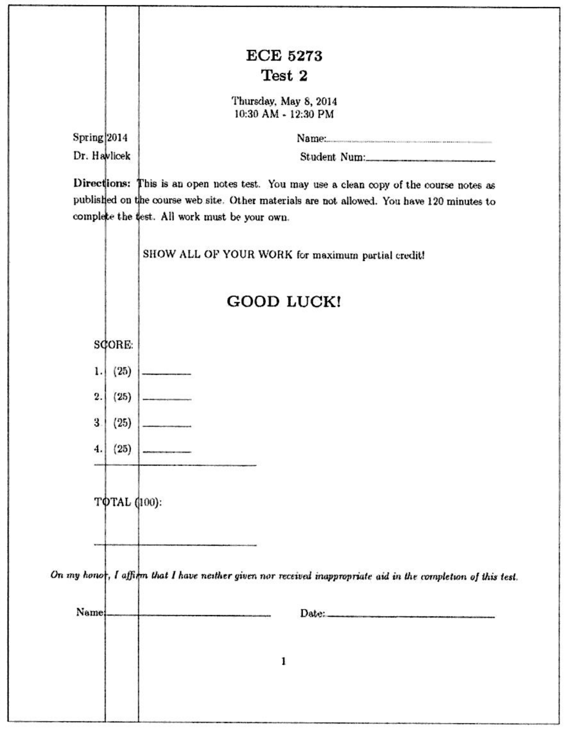
Name: ____________ Date: ____________

1. **25 pts.** True or False. Mark *True* only if the statement is **always** true.

TRUE	FALSE	
	X	(a) **2 pts.** When a fast implementation is required, median filters are usually designed using the frequency sampling technique. Nonlinear filters don't have a frequency response.
X		(b) **2 pts.** To implement the linear convolution of two $M \times N$ images by pointwise multiplication of DFT's, the images must be zero padded to a size of at least $(2M-1) \times (2N-1)$.
	X	(c) **2 pts.** To implement the wraparound convolution of two $M \times N$ images by pointwise multiplication of DFT's, the images must be zero padded to a size of at least $2M \times 2N$. both wrong
X		(d) **2 pts.** The main idea of homomorphic filtering is to transform a multiplicative noise problem into an additive noise problem.
X		(e) **2 pts.** For both Gaussian and Laplacian noise, the trimmed mean filter $\text{TM}_{p/2}$ reduces the variance by a factor $> (0.9) \cdot \text{OPTIMAL}$.
	X	(f) **2 pts.** The main reason that MSE has traditionally been used as a figure of merit for image denoising is that it agrees well with human visual perception.
	X	(g) **2 pts.** The frequency response of the CLOSE-OPEN filter exhibits a "low-pass" characteristic. Nonlinear filter — no freq resp.
X		(h) **2 pts.** For linear image deblurring, the optimal deconvolution filter is usually a high-pass filter.
X		(i) **2 pts.** The binary version of any stack filter is a positive boolean function.
	X	(j) **2 pts.** The main advantage of the gradient-based edge detectors is that they perform well on noisy images.
X		(k) **2 pts.** Run-length coding of the quantized DCT coefficients is probably the greatest source of compression in baseline JPEG.
	X	(l) **3 pts.** The Wiener filter was developed by the Oscar Mayer Company for processing images from the forward looking camera in their famous Wienermobiles.

2. **25 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:





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1. (25)
2. (25)
3. (25)
4. (25)

TOTAL (100):

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Name: Date:

1

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.

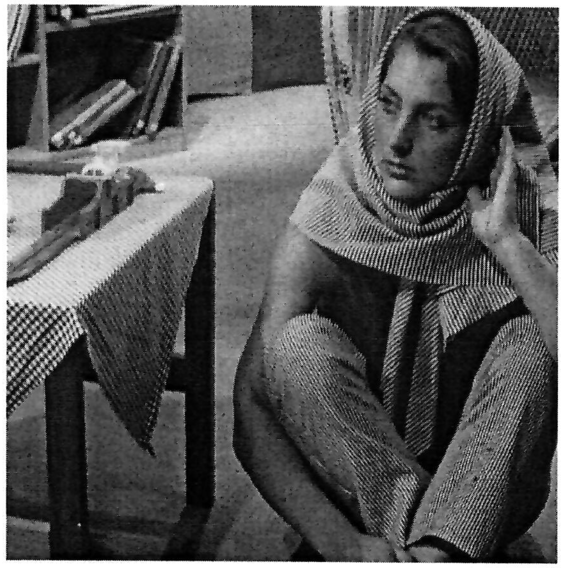
The window should be as small as possible to avoid making unnecessary changes to the good pixels

Since the "bad" lines are always vertical, always one pixel wide, and always separated by at least 64 colums, a ROW(2P+1) window will be sufficient to remove them. ROW(3) is the smallest window that will work.

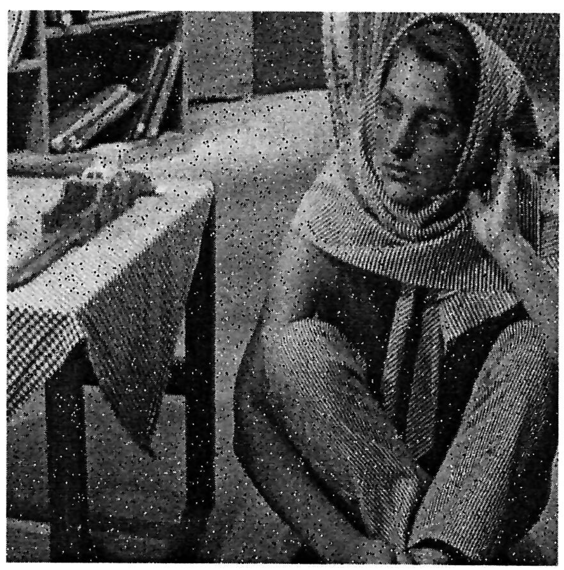
As can be seen in the example images, the "bad" black lines will generally cross over both bright and dark structure in the image. MEDIAN will replace the "bad" pixels with a value that is similar to the majority of the pixels in the local image structure. Also, it will not blur edges

Use MEDIAN with window B = ROW(3).

3. **25 pts**. Consider the original 512×512 grayscale *Barbara* image $\mathbf{I}$ shown below:



Each pixel has 8 bits. During transmission, the image is corrupted by salt-and-pepper noise and additive white Gaussian noise with standard deviation $\sigma = 12$. The received image $\mathbf{J} = \mathbf{I} + \mathbf{N}$ is shown below:



Problem 3, cont...

The following seven filters are applied to $\mathbf{J}$ in an effort to restore the image by denoising:

(a) $\mathbf{K} = \text{AVE}[\mathbf{J}, \mathbf{B}]$, with $\mathbf{B} = \text{SQUARE}(25)$.

(b) $\mathbf{K} = \text{MED}[\mathbf{J}, \mathbf{B}]$, with $\mathbf{B} = \text{SQUARE}(25)$.

(c) $\mathbf{K} = \text{CLOSE}[\mathbf{J}, \mathbf{B}]$, with $\mathbf{B} = \text{SQUARE}(25)$.

(d) $\mathbf{K} = \text{OPEN}[\mathbf{J}, \mathbf{B}]$, with $\mathbf{B} = \text{SQUARE}(25)$.

(e) $\mathbf{K} = \text{CLOS-OPEN}[\mathbf{J}, \mathbf{B}]$, with $\mathbf{B} = \text{SQUARE}(25)$.

(f) A 128×128 linear Gaussian low-pass filter with space constant $\sigma = 3$, similar to Example 3 on page 5.61 of the course notes.

(g) A 256×256 linear Gaussian high-pass filter with space constant $\sigma = 48$, similar to Example 6 on page 5.79 of the course notes.

Filters (a)-(e) are implemented directly in the space domain with edge effects handled by replication. Filters (f) and (g) are implemented by pointwise multiplication of DFT's with appropriate zero padding to obtain linear convolution.

Label the seven filtered images shown below on pages 7-10.

CLOS-OPEN

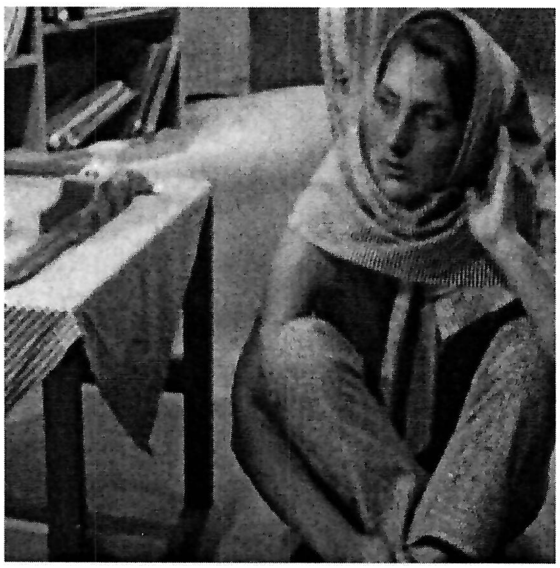
- There is a lot of smoothing, but the edges are sharp → can't be 5x5 average or Gaussian low-pass.

- The image is over smoothed, because there are actually four 5x5 operations being applied; two dilations and two erosions.

Problem 3, cont...

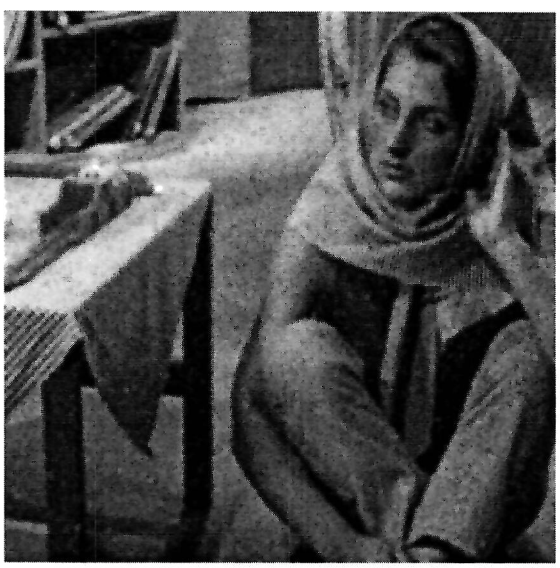
Gaussian Low-Pass.

- removes the noise, but blurs the edges
- The dark bands around the edges of the image indicate zero padding and <u>not</u> replication... so this is <u>not</u> the AVE filter.



MEDIAN.

- removes the salt-and-pepper noise and the Gaussian noise without blurring the edges.
- Some of the stripes are lost because the window is 5x5.



AVE

- only slight blurring.
- Gaussian noise effectively removed.
- but salt-and-pepper noise artifacts remain.

Problem 3, cont...

OPEN

- because erosion is done first, "salt" is removed but "pepper" artifacts remain.

Gaussian high-pass.

- The noise is amplified instead of attenuated.

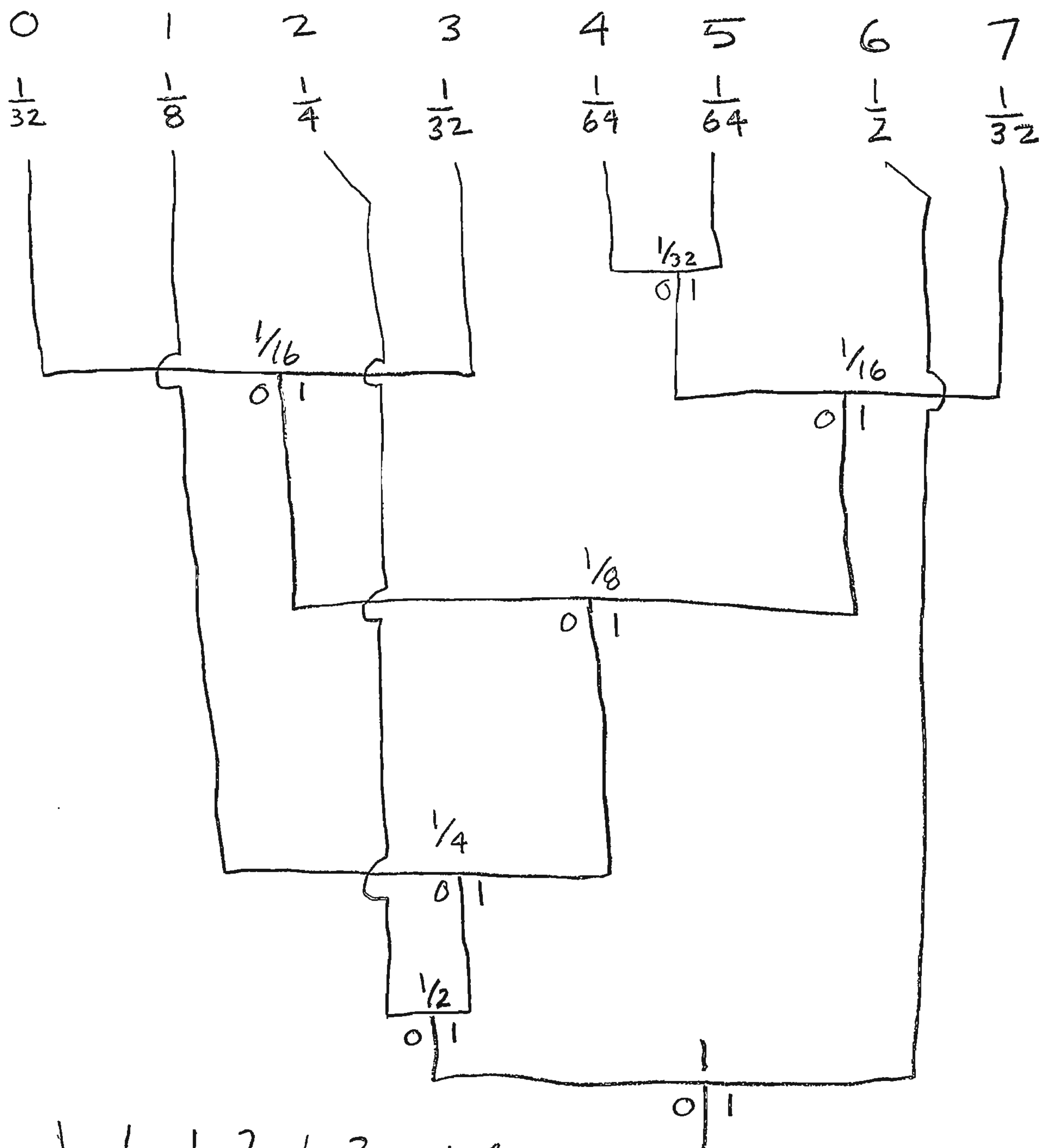
CLOSE

- because dilation is done first, "pepper" is removed but "salt" artifacts remain.

4. **25 pts.** Gray scale digital images **I** with 3 bits per pixel and gray levels in the range $\{0, 1, \ldots, 7\}$ 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
$p_{\mathbf{I}}(k)$	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{64}$	$\frac{1}{2}$	$\frac{1}{32}$

(a) **15 pts.** Design a Huffman code to encode these images.



	0	1	2	3	4	5	6	7
$\hat{k}_k$	01100	010	00	01101	011100	011101	1	01111
$L(\hat{k}_k)$	5	3	2	5	6	6	1	5

Problem 4 cont...

(b) **5 pts.** Find the expected BPP (bits per pixel) and CR (compression ratio) for the coded images $C(\mathbf{I})$.

original BPP = 3

coded BPP = $\sum_{k=0}^{7} p_I(k) L(\hat{k}_k)$

$$= (\tfrac{1}{32})5 + (\tfrac{1}{8})3 + (\tfrac{1}{4})2 + (\tfrac{1}{32})5 + (\tfrac{1}{64})6 + (\tfrac{1}{64})6 + (\tfrac{1}{2})1 + (\tfrac{1}{32})5$$

$$= \frac{5}{32} + \frac{3}{8} + \frac{2}{4} + \frac{5}{32} + \frac{6}{64} + \frac{6}{64} + \frac{1}{2} + \frac{5}{32}$$

$$= \frac{5+12+16+5+3+3+16+5}{32} = \frac{65}{32} = \underline{2.03125}$$

$$CR = \frac{3}{2.03125} = \underline{1.47692}$$

(c) **5 pts.** Does your code achieve the theoretical lower bound on BPP for the coded images? Explain why or why not.

<u>YES</u>. Since all the symbol probabilities are powers of two, this code achieves the theoretical lower bound on BPP.