# ECE 5273
# Test 1

Tuesday, March 31, 2026
4:30 PM - 5:45 PM

Spring 2026 Name: SOLUTION

Dr. Havlicek Student Num:__________

**Directions:** This is an open notes test. You may use the official course lecture notes and a calculator. Other materials are not allowed. You have 75 minutes to complete the test. All work must be your own.

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) **2 pts.** Ultrasound is an example of reflection imaging. NOTES p. 1.22 |
| | X | (b) **2 pts.** Frame averaging can usually be used to reduce noise when there is rapid motion in the scene. NOTES p. 3.52 |
| X | | (c) **2 pts.** The binary median filter is self-dual with respect to complementation. NOTES p. 2.83 |
| X | | (d) **2 pts.** The binary OPEN-CLOSE filter tends to link neighboring objects together. NOTES p. 2.93 |
| | X | (e) **2 pts.** Histogram flattening (equalization) can be used to transform any digital image $\mathbf{I}$ into a new digital image $\mathbf{K}$ with a perfectly flat histogram. NOTES pp. 3.36 – 3.40 |
| X | | (f) **2 pts.** While run-length coding often reduces the amount of memory needed to store a binary image, there are cases where it can actually increase the required storage. NOTES p. 2.105 |
| X | | (g) **2 pts.** For a practical digital image $\mathbf{I}$, the 2D DFT $\widetilde{\mathbf{I}}$ is given by equally spaced samples of the DSFT $\widetilde{\mathbf{I}}_D$. NOTES p. 4.108 |
| X | | (h) **2 pts.** If $\mathbf{I}$ is a digital image that is real, then the DFT $\widetilde{\mathbf{I}}$ is conjugate symmetric. NOTES p. 4.59 |
| X | | (i) **2 pts.** Multilayer perceptrons (MLP's) and artificial neural networks (ANN's) are tools to construct algorithms that learn from data (training) and make predictions (testing). NOTES p. 3.86 |
| OH | MY! | (j) **2 pts.** The Iranian regime can be overthrown without a ground war. |

2. **20 pts.** Consider the $4 \times 4$ image **I** shown below, where the allowable range of gray levels is $0 \leq I(i,j) \leq 15$:

**I** =

| | | | |
|---|---|---|---|
| **10** | **3** | **2** | **1** |
| **4** | **3** | **2** | **10** |
| **3** | **4** | **9** | **9** |
| **2** | **1** | **4** | **9** |

Construct a new image **K** by applying the histogram flattening (equalization) algorithm. Show the new image **K** and its histogram $H_{\mathbf{K}}$ in the spaces provided below.

**K** =

| | | | |
|---|---|---|---|
| 15 | 6 | 3 | 0 |
| 10 | 6 | 3 | 15 |
| 6 | 10 | 13 | 13 |
| 3 | 0 | 10 | 13 |

Work is shown on the next page

| $k$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_{\mathbf{K}}(k)$ | 2 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 2 |

Work space is provided on the next page.

**Workspace for Problem 2:**

$I =$

| | | | |
|---|---|---|---|
| 10 | 3 | 2 | 1 |
| 4 | 3 | 2 | 10 |
| 3 | 4 | 9 | 9 |
| 2 | 1 | 4 | 9 |

| | | | |
|---|---|---|---|
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For I:

| $k$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H($k$) | 0 | 2 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 |
| p($k$) | 0/16 | 2/16 | 3/16 | 3/16 | 3/16 | 0 | 0 | 0 | 0 | 3/16 | 2/16 | 0 | 0 | 0 | 0 | 0 |
| P($k$) | 0 | 2/16 | 5/16 | 8/16 | 11/16 | 11/16 | 11/16 | 11/16 | 11/16 | 14/16 | 16/16 | 1 | 1 | 1 | 1 | 1 |

For K:

| $k$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H($k$) | 2 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 2 |
| p($k$) | | | | | | | | | | | | | | | | |
| P($k$) | | | | | | | | | | | | | | | | |

$J = P_I(I) =$

| | | | |
|---|---|---|---|
| 1 | 8/16 | 5/16 | 2/16 |
| 11/16 | 8/16 | 5/16 | 1 |
| 8/16 | 11/16 | 14/16 | 14/16 |
| 5/16 | 2/16 | 11/16 | 14/16 |

| J(m,n) | K(m,n) |
|---|---|
| 2/16 | 0 |
| 5/16 | 3 |
| 8/16 | 6 |
| 11/16 | 10 |
| 14/16 | 13 |
| 1 | 15 |

| | | | |
|---|---|---|---|
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| | | | |
| | | | |

$K =$

| | | | |
|---|---|---|---|
| 15 | 6 | 3 | 0 |
| 10 | 6 | 3 | 15 |
| 6 | 10 | 13 | 13 |
| 3 | 0 | 10 | 13 |

| | | | |
|---|---|---|---|
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$K = \text{FSCS}(J)$ [Notes p. 3.15]

$A = \min(J) = 2/16 = 1/8$

$B = \max(J) = 1$

K = No. gray levels = 16

$K-1 = 15$

$$P = \frac{K-1}{B-A} = \frac{15}{1-2/16} = \frac{15}{7/8} = \frac{8\cdot 15}{7}$$

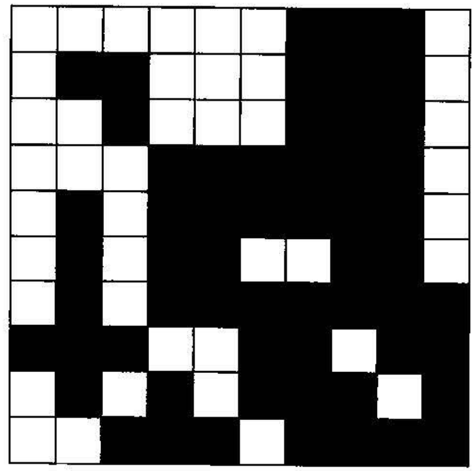
$$K(m,n) = \text{round}\{P[J(m,n) - A]\}$$

$$= \text{round}\left\{\frac{8\cdot 15}{7}[J(m,n) - 1/8]\right\}$$

$$= \text{round}\left\{\frac{15}{7}[8J(m,n) - 1]\right\}$$

3. **20 pts.** Consider the 10 $\times$ 10 binary image $\mathbf{I}$ shown below, where BLACK = LOGIC ONE and WHITE = LOGIC ZERO.

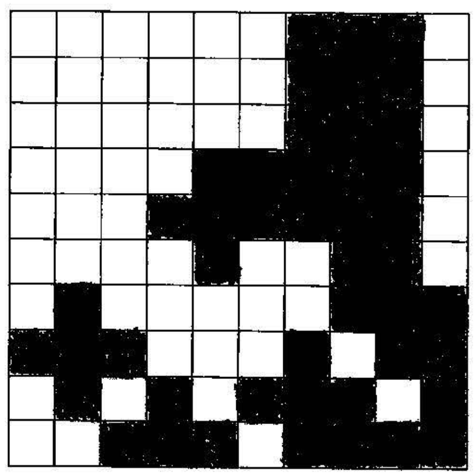
$\mathbf{I}$ =



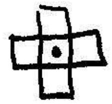
Form a new binary image $\mathbf{J} = \text{OPEN}(\mathbf{I}, \mathbf{B})$ by applying a binary morphological OPEN filter with structuring element $\mathbf{B} = \text{CROSS}(5)$. Handle edge effects by replication.

Show the new image $\mathbf{J}$ in the space provided below:

$\mathbf{J}$ =



There is work space on the next page.

B = 

**Workspace for Problem 3:**

I

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |

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ERODE(I, B):

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 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 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |

J = DILATE [ERODE (I, B), B]

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |

4. **20 pts.** Consider a $6 \times 6$ digital image $\mathbf{I}$ given by

$$I(m,n) = 1 + 2\cos\left[\frac{2\pi}{6}(m+2n)\right] + 2\sin\left[\frac{2\pi}{6}(2m-n)\right],$$

where $m$ = column and $n$ = row.

(a) **10 pts.** Find a closed form expression for the DFT $\tilde{\mathbf{I}}$.

NOTES p. 4.126 : $1 \leftrightarrow 1 \cdot 6 \cdot 6 \cdot \delta(u,v) = 36\,\delta(u,v)$

NOTES p. 4.128 : $2\cos\left[2\pi\left(\frac{1}{6}m + \frac{2}{6}n\right)\right] \leftrightarrow \frac{2}{2}\cdot 6 \cdot 6\left[\delta(u-1,v-2) + \delta(u+1,v+2)\right]$

$= 36\left[\delta(u-1,v-2) + \delta(u+1,v+2)\right]$

NOTES p. 4.129 : $2\sin\left[2\pi\left(\frac{2}{6}m - \frac{1}{6}n\right)\right] \longleftrightarrow j\,\frac{2}{2}\cdot 6 \cdot 6\left[\delta(u+2,v-1) - \delta(u-2,v+1)\right]$

$= j36\left[\delta(u+2,v-1) - \delta(u-2,v+1)\right]$

$$\tilde{I}(u,v) = 36\delta(u,v) + 36\left[\delta(u-1,v-2) + \delta(u+1,v+2)\right] + j36\left[\delta(u+2,v-1) - \delta(u-2,v+1)\right]$$

(b) **10 pts.** Show the real and imaginary parts of the **centered** DFT array in the space provided below:

$\tilde{\mathbf{I}}$ =

| v \ u | -3 | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|---|
| -3 | 0 | 0 | 0 | 0 | 0 | 0 |
| -2 | 0 | 0 | 36 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 36 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 36 | 0 |

+ $j \times$

| v \ u | -3 | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|---|
| -3 | 0 | 0 | 0 | 0 | 0 | 0 |
| -2 | 0 | 0 | 0 | 0 | 0 | 0 |
| -1 | 0 | 0 | 0 | 0 | 0 | -36 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 36 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |

5. **20 pts.** Draw lines to match the images with their log-magnitude DFT spectra.