Fill out your **Student ID** on every page:

C	S	1	1	1	D	I	P

CS 111: Digital Image Processing
Spring 2019
Final Exam: June 12th, 2019

Time: 2 hours Total Points: 120

Name (in BLOCK LETTERS): ________PETER THE ANTEATER________________________________

Seat Assignment: __________

Pledge: I neither received nor gave any help from or to anyone in this exam.

Signature: ________________________________

Useful Tips

1. All questions are multiple choice questions. Please indicate your answers clearly. You may circle them or write out the exact choice. If your choice is unclear or ambiguous, you will not receive credit for your answer.
2. **All questions may have more than one correct answer. You must select all the correct answers for full credit.**
3. Use the blank pages as your worksheet. Put the question number when working out the steps in the worksheet. Do your work clearly. This will help in awarding partial credit. Answer the questions you are most comfortable with first.
4. **Points are indicative of the time in minutes you should spend on the question.**
5. **Ensure that your exam has pages numbered 1 to 20.**
6. Please ask for extra sheets if you need more.
7. Staple all your worksheets together with the paper when submitting at the end of the exam. If pages of your exam are missing since you took them apart, we are not responsible for putting them together.
8. **In the interest of fairness, we will not be answering any queries regarding the exam questions. If you are uncertain about something, clearly state your assumption and solve the question accordingly.**

Do not enter anything in the table below

Q #	Points	Points Received	Q #	Points	Points Received
1)	**7**		14)	**3**	
2)	**12**		15)	**9**	
3)	**6**		16)	**5**	
4)	**7**		17)	**7**	
5)	**12**		**Bonus**	**5**	
6)	**6**				
7)	**14**				
8)	**8**				
9)	**5**				
10)	**4**				
11)	**3**				
12)	**6**				
13)	**6**		**Total**	**125**	

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COMPRESSION [7+12+6=25]

1) [1+2+2+1+1=7] Consider a JPEG compression pipeline using 6x6 image blocks instead of 8x8. The coefficients generated by doing a DCT on a 6x6 block of luminance values is denoted by *D.* The quantization table is denoted by *Q.*

a. The quantized values are computed by:
   i. $D(i,j)/Q(i,j)$
   ii. $Q(i,j)/D(i,j)$
   iii. $Round(Q(i,j)/D(i,j))$
   iv. $Round(D(i,j)/Q(i,j))$

b. If the quantized values are given by the following 6x6 block:

35	3	1	1	0	0
2	1	0	0	0	0
2	1	0	0	0	0
1	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

then the stream to be transmitted is:
   i. **35, 3, 2, 2, 1, 1, 1, 0, 1, 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, 0, 0**
   ii. 35, 2, 2, 1, 0, 0, 3, 1, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
   iii. 35, 3, 1, 1, 0, 0, 2, 1, 0, 0, 0, 0, 2, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

c. The stream in (b) after run-length encoding is:
   i. **35, 3, (2, 2), (1, 3), 0, (1, 2), (0, 26)**
   ii. 35, 3, (1, 2), (0, 2), 2, 1, (0, 4), 2, 1, (0, 4), 1, (0, 17)
   iii. 35, 2, 2, 1, 0, 0, 3, 1, 1, (0, 3), 1, (0, 5), 1, (0, 17)
   iv. 35, 3, 2, 2, (1, 3), 0, 1, 1, (0, 26)

d. To improve the quality of the decoded image, the values in the quantization table should be:
   i. Increased
   ii. **Decreased**
   iii. Kept the same

e. The improvement in (d) comes at the cost of:
   i. **Reduced compression**
   ii. A more complex decoding method
   iii. A larger quantization table
   iv. **Larger storage**

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2) [1+2+4+1+1+3=12] Consider the text "*hip hip hurray*". This text has seven different characters, namely '*h*', '*i*', '*p*', '*u*', '*r*', '*a*', '*y*', and the *space* character.

a. To encode this text using ASCII representation (8 bits/character), how many bits will be needed?
   i. 80
   ii. 88
   iii. **112**

b. The character(s) with the highest frequency(ies) is/are:
   i. ***h***
   ii. *r*
   iii. *space*
   iv. *h* and *r*
   v. *h, r* and *space*

c. What is the height of the binary tree formed to find the Huffman coding for this text? (**Note:** The height of a tree is the number of edges on the *longest path* from the root to a leaf. Please show your tree in the scratch work for full credit).
   i. 3
   ii. **4**
   iii. 5

d. The length of the shortest code is:
   i. 1 bit
   ii. **2 bits**
   iii. 3 bits
   iv. 4 bits
   v. 5 bits

e. The length of the longest code is:
   i. 1 bit
   ii. 2 bits
   iii. 3 bits
   iv. **4 bits**
   v. 5 bits

f. The average code length of a character is given by:
   i. 3 bits/character
   ii. $\frac{41}{14}$ **bits/character**
   iii. 4 bits/character

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3) [1+2+2+1=6] Consider a color image with 24 bpp (*bits per pixel*).

a. We apply the simplest compression technique of throwing away the 3 least significant bits per channel. What will be the bpp for the compressed image?
   i. 12 bpp
   ii. **15 bpp**
   iii. 16 bpp
   iv. 21 bpp

b. The compression in this case is:
   i. 12.5%
   ii. 37.33%
   iii. 50.0%
   iv. **62.5%**

c. Consider a 4x4 macroblock. We subsample the *UV* to 2x2 while retaining the entire macroblock for *Y*. The bpp of the compressed stream is approximately:
   i. 7 bpp
   ii. **12 bpp**
   iii. 15 bpp
   iv. 21 bpp

d. This leads to a compression of approximately:
   i. 40%
   ii. **50%**
   iii. 70%
   iv. 90%

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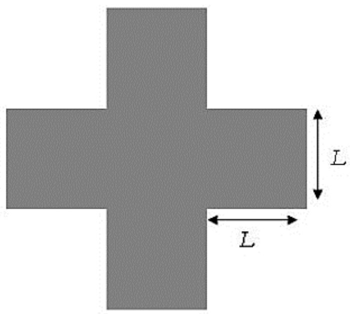
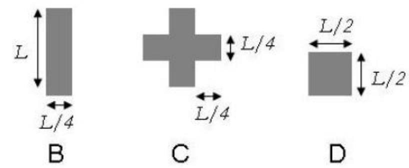
MORPHOLOGICAL OPERATORS [7+4+4+6=21]

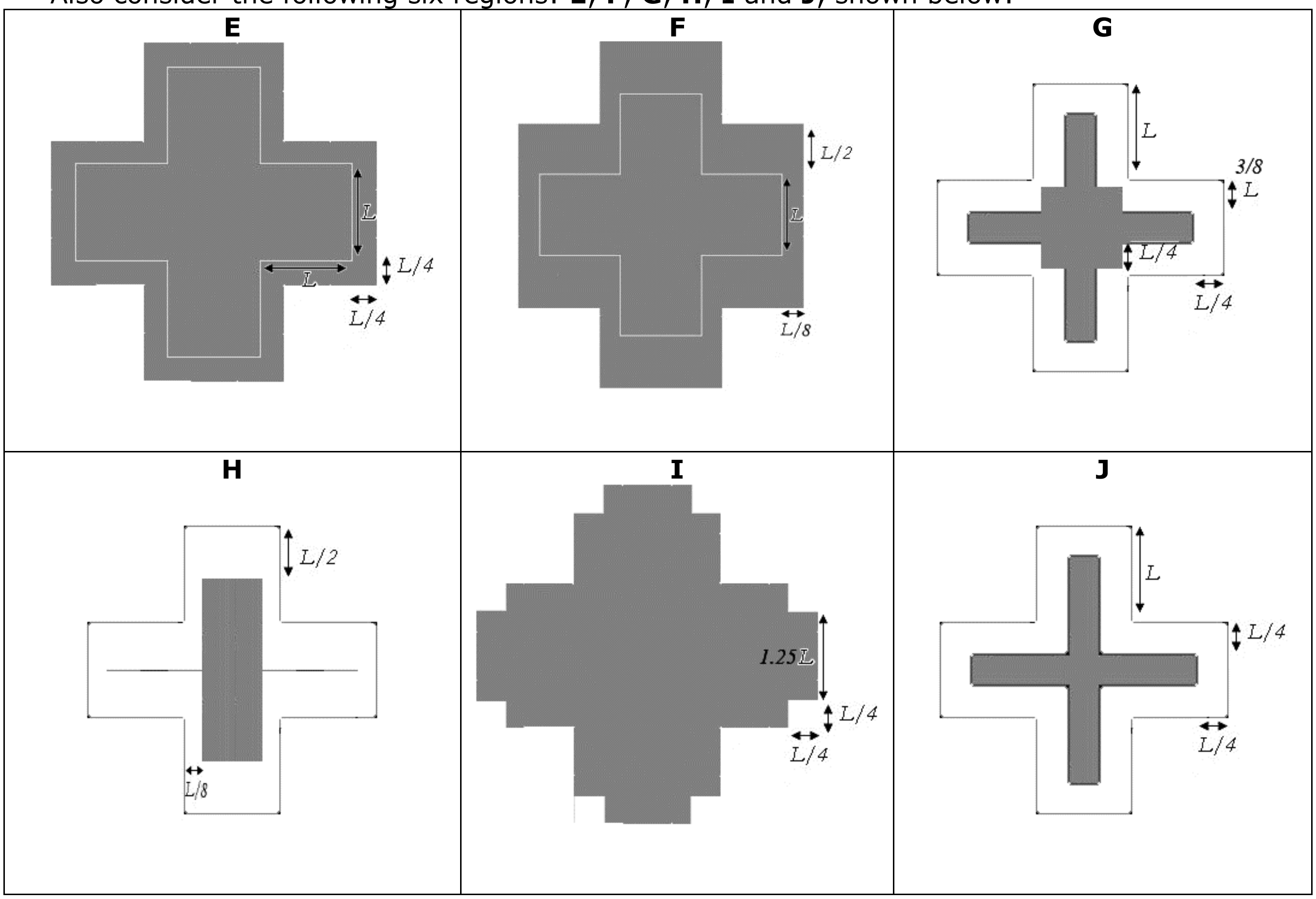
4) [3+2+2=7] Consider the region **A** and the structuring elements **B**, **C** and **D**, shown below.

A





Also consider the following six regions: **E**, **F**, **G**, **H**, **I** and **J**, shown below:



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C	**S**	**1**	**1**	**1**	**D**	**I**	**P**

a. The dilation and erosion of **A** with **B** would result in which of the following?

   i. **E** and **H**
   ii. **F** and **H**
   iii. **E** and **J**
   iv. **F** and **J**

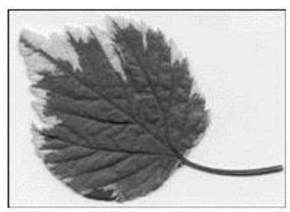
b. **G** is the result of:

   i. **Erosion with C**
   ii. Dilation with **C**
   iii. Erosion with **B**
   iv. Dilation with **D**

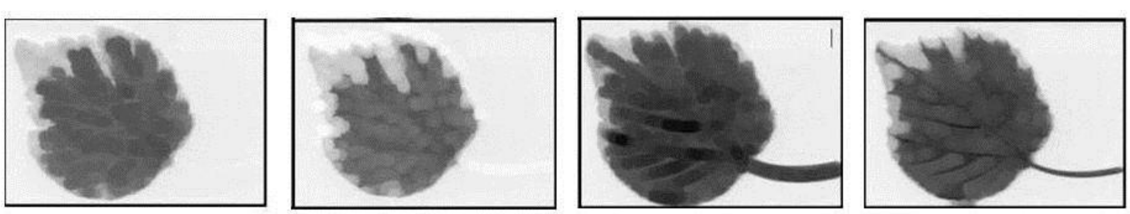
c. The dilation of **G** with **C** will have a shape similar to:

   i. **I**
   ii. **E**
   iii. **F**
   iv. **H**

5) [4] Consider the following gray scale image.



Each of the following images is obtained by applying one of the operations of erosion, dilation, opening and closing on the above image. Match the results with the operations by drawing lines between them. **(1) Closing (2) Dilation, (3) Erosion, (4) Opening**



Erosion   Dilation   Opening   Closing

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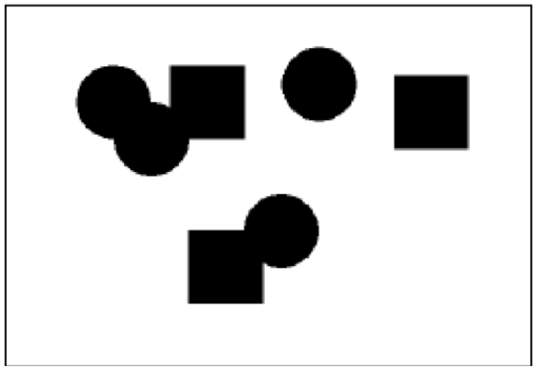
C	S	1	1	1	D	I	P

6) [2+2=4] Consider the following image. The radius *r* of the circles in this image is half the length *l* of the squares. The set of black pixels, denoted by *A*, is shown below:



a. Erosion of *A* by a structuring element identical to the circle (i.e. a circle of radius *r*) will result in how many connected components?
   - *i.* **3**
   - *ii.* 4
   - *iii.* 7

b. Erosion of *A* by a structuring element which is a circle of radius *(r-1)* pixels will result in how many connected components?
   - *i.* 3
   - *ii.* 4
   - *iii.* **7**

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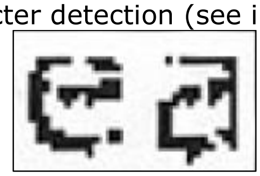
7) [1+1+2+2=6] Consider the following operations on an image and indicate the combination of the basic morphological operators that would achieve them.

a. Edge detection is given by:
   - *i.* **Dilation – Erosion**
   - *ii.* Erosion – Dilation
   - *iii.* Opening – Closing
   - *iv.* Closing – Opening

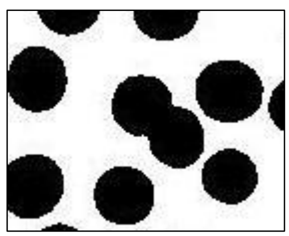
b. Smoothing is given by:
   - *i.* **Opening followed by Closing**
   - *ii.* Erosion followed by Dilation
   - *iii.* Opening followed by Dilation
   - *iv.* Erosion followed by Closing

c. Connecting broken edges in character detection (see image below) can be done by:



   - *i.* **Dilation**
   - *ii.* Erosion
   - *iii.* Opening
   - *iv.* Closing

d. Separating overlapped cells in a microscopic image (shown below) before cell counting can be done by:



   - *i.* Dilation
   - *ii.* **Erosion**
   - *iii.* Opening
   - *iv.* Closing

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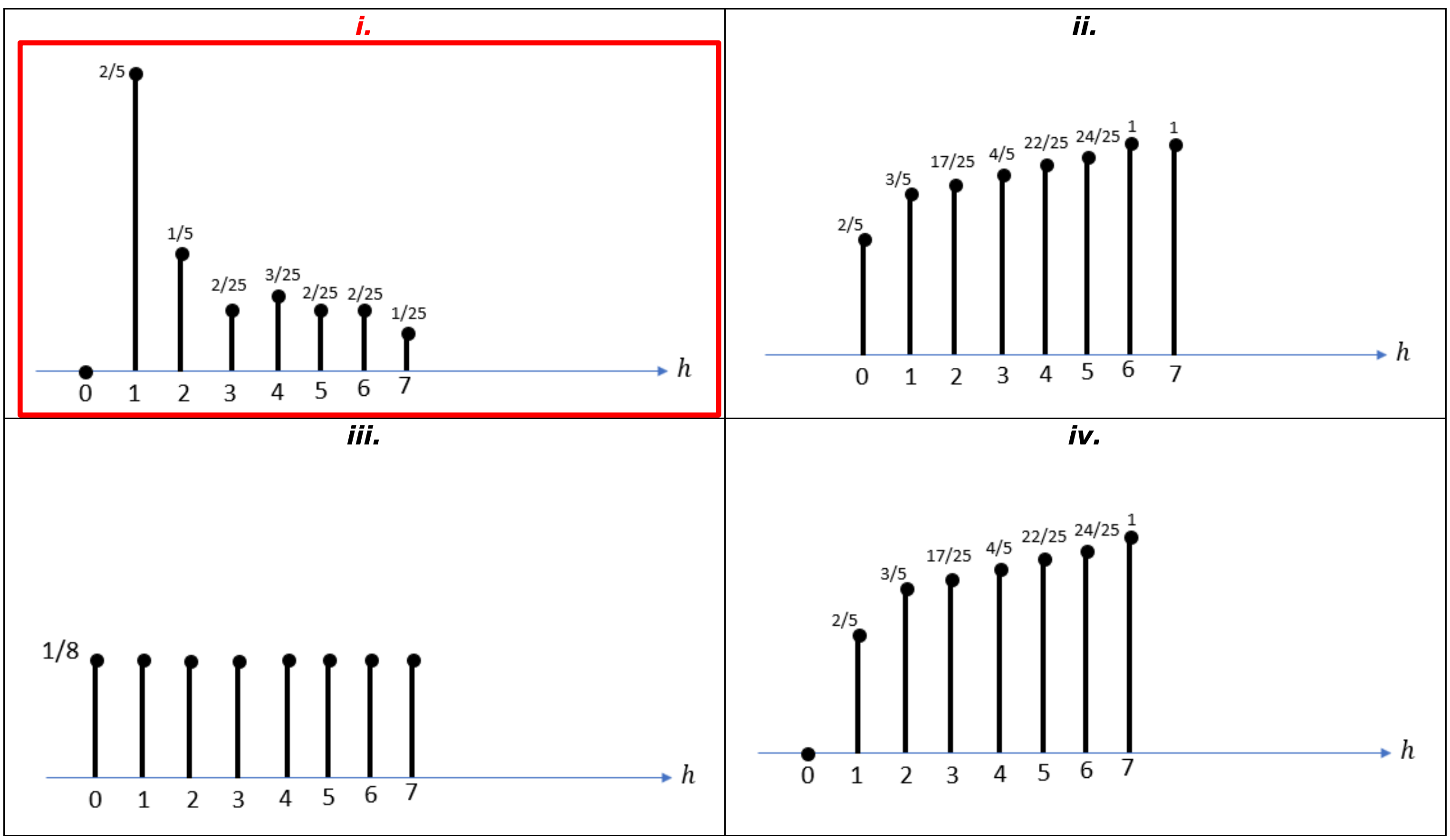
HISTOGRAM PROCESSING [14]

8) [4+4+2+2+2=14] Consider the following 5x5 image with gray levels between [0 … 7]:

7	6	2	1	2
6	5	2	2	2
5	4	1	1	1
4	4	1	1	1
3	3	1	1	1

a. The histogram (PDF) of this image is given by which of the following plots?



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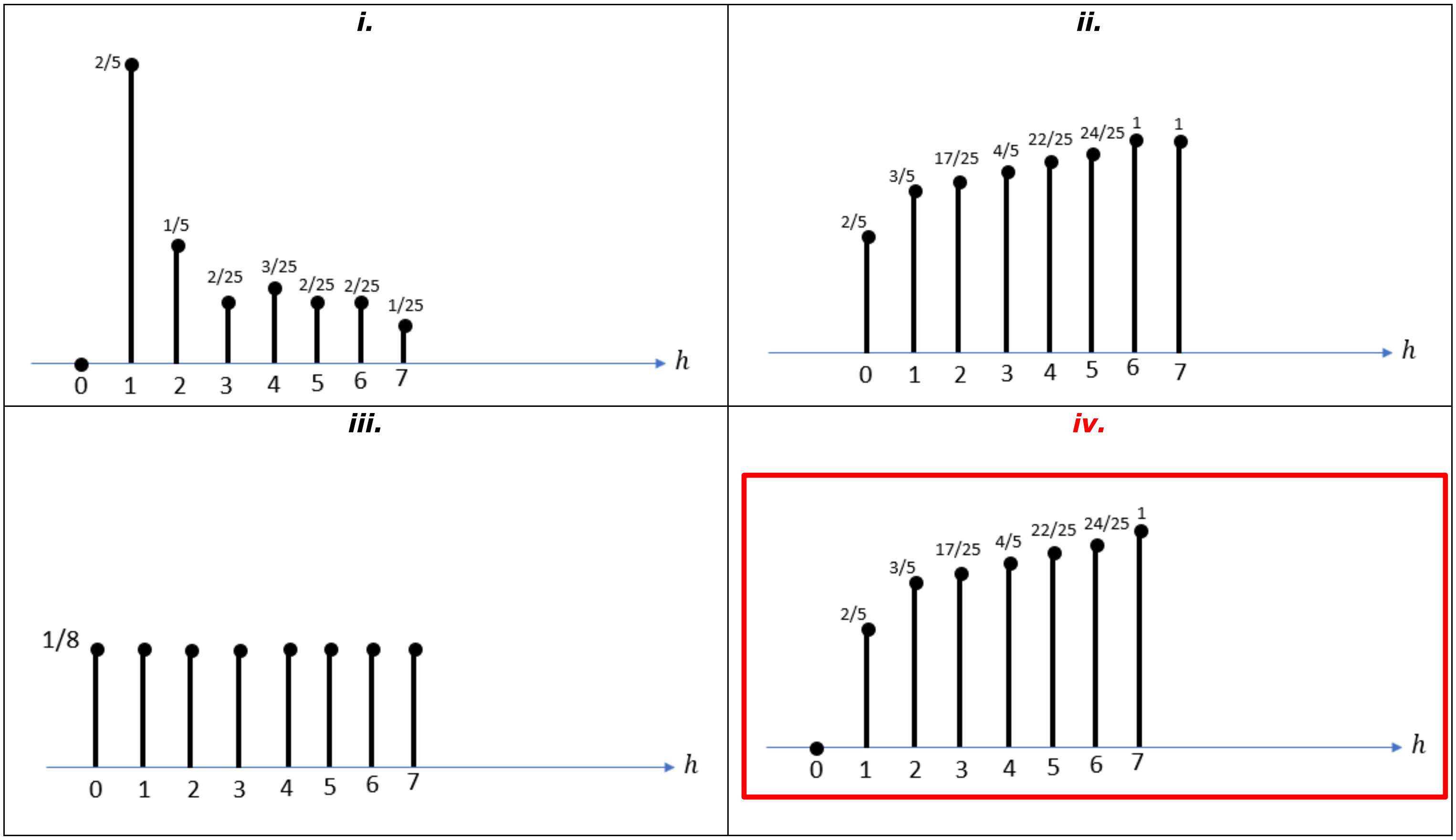
b. The cumulative histogram (CDF) of this image is given by which of the following plots?



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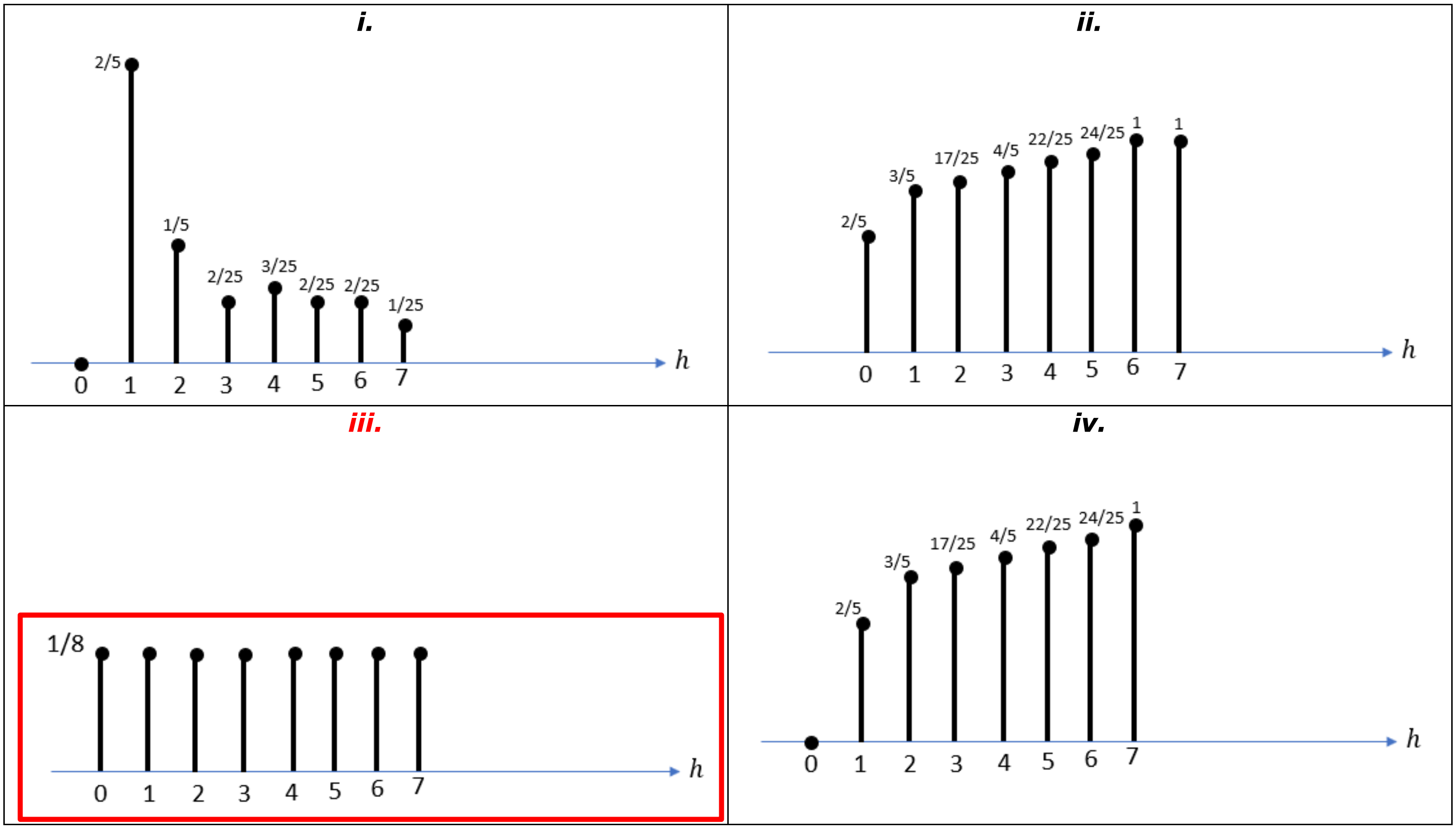
C	S	1	1	1	D	I	P

c. In order to perform histogram equalization, the target histogram ~~CDF~~ PDF should be:



d. After performing the histogram equalization, input gray value of 0 will be mapped to the new gray value of:

i. **0**
ii. 1
iii. 2
iv. 3

e. After performing the histogram equalization, input gray value of 1 will be mapped to the new gray value of:

i. 0
ii. 1
iii. **2**
iv. 3

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IMAGE TRANSFORMATION [8+5=13]

9) [2+2+1+1+2=8] Consider an image which first undergoes counterclockwise rotation ***R*** of *90°* followed by a scaling ***S*** of *3* in both directions.

a. The rotation ***R*** is given by:
   - *i.* $[1\ 0\ 0\ -1]$
   - *ii.* $[1\ 0\ 0\ 1]$
   - *iii.* $[0\ -1\ 1\ 0]$
   - *iv.* $[0\ 1\ -1\ 0]$

b. The scale ***S*** is given by:
   - *i.* $[3\ 0\ 0\ 3]$
   - *ii.* $[1\ 3\ 3\ 1]$
   - *iii.* $[\sqrt{3}\ 0\ 0\ \sqrt{3}]$
   - *iv.* $[\sqrt{3}\ 1\ 1\ \sqrt{3}]$

c. Next, the image is translated. To apply a translation ***T*** of *(2,4)*, which of the following kind(s) of representation must we use to represent ***T*** as a transformation matrix?
   - *i.* Cartesian Coordinates
   - *ii.* Polar Coordinates
   - *iii.* **Homogeneous Coordinates**

d. Using the representation(s) in (c), the dimensions of ***T*** will be:
   - *i.* 1x1
   - *ii.* 2x2
   - *iii.* **3x3**
   - *iv.* 4x4

e. The combined effect ***M*** of these three transformations ***R, S*** and ***T*** is given by:
   - *i.* *TRS*
   - *ii.* *T+R+S*
   - *iii.* ***TSR***
   - *iv.* *R+S+T*

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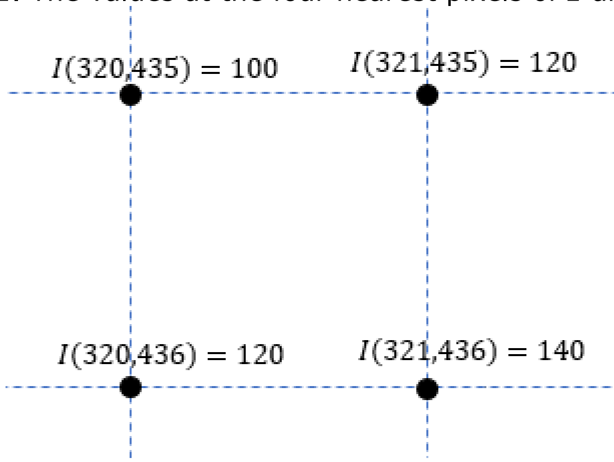
10) [2+2+1=5] A pixel in a geometrically transformed image corresponds to the pixel *(320.1, 435.5)* in the original image ***I***. The values at the four nearest pixels of ***I*** are given as:



a. The value at ***I****(320.1, 435)* is:
   - *i.* *100*
   - *ii.* *101*
   - *iii.* ***102***
   - *iv.* *120*

b. The value at ***I****(320.1, 436)* is:
   - *i.* *102*
   - *ii.* *120*
   - *iii.* ***122***
   - *iv.* *124*

~~c. The value at ***I****(320.1, 436.5)* is:~~
   - ~~*i.* *101*~~
   - ~~*ii.* *103*~~
   - ~~*iii.* *111*~~
   - ~~*iv.* *113*~~

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CONVOLUTION [8]

11) [2+2+2+2=8] Consider an image of size $m \times n$ and a filter of size $k \times k$, where k is an odd integer. The center of the filter is the origin.

a. How many multiplications are performed during this filtering?
   - *i.* $m \times n$
   - *ii.* $m \times n \times k$
   - *iii.* $m \times n \times k^2$
   - *iv.* $m \times n \times \frac{k}{2}$

b. How many multiplications are performed if the filter size is changed to $k \times 1$?
   - *i.* $m \times n$
   - *ii.* $m \times n \times k$
   - *iii.* $m \times n \times k^2$
   - *iv.* $m \times n \times \frac{k}{2}$

c. Suppose the $k \times k$ filter can be constructed by convolving a $k \times 1$ filter and a $1 \times k$ filter. What is the total number of multiplications performed if we convolve the image with a $k \times 1$ filter and then by a $1 \times k$ filter?
   - *i.* $2 \times m \times n$
   - *ii.* $2 \times m \times n \times k$
   - *iii.* $m^2 \times n^2 \times k$
   - *iv.* $m^2 \times n^2 \times k^2$

d. Convolution by separating a filter is possible because convolution is:
   - *i.* Commutative
   - *ii.* **Associative**
   - *iii.* Distributive

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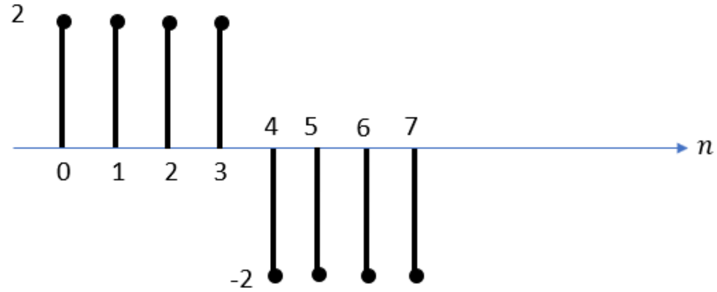
SPECTRAL IMAGE ANALYSIS [3+3+8=14]

12) **[1+1+1=3]** Consider the following discrete signal *x[n]* with length *N* = 8.



a. What is the D.C. value?

   i. -2

   ii. **0**

   iii. 1/8

   iv. 2

b. What is the frequency component of the signal that has the highest amplitude?

   i. 0

   ii. $Cos(\frac{\pi n}{4})$

   iii. $Cos(\frac{\pi n}{2})$

   iv. $Cos(\pi n)$

c. What is the frequency of a sinusoidal that makes 4 cycles within 8 samples?

   i. 0

   ii. $Cos(\frac{\pi n}{4})$

   iii. $Cos(\frac{\pi n}{2})$

   iv. $Cos(\pi n)$

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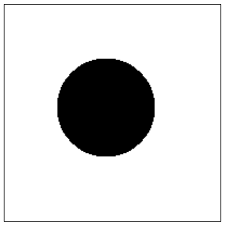
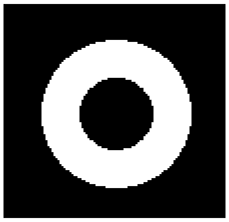
13) **[1+1+1=3]** Consider a box filter in the spatial domain.

a. Multiplication of the disc on the right (black: 0, white: 1) with a signal's DFT in *frequency domain* achieves:



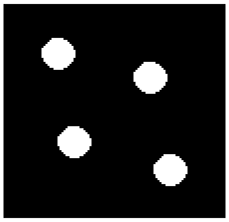
i. Low Pass filter
ii. **High Pass filter**
iii. Band Pass filter
iv. Notch filter

b. Multiplication of the donut on the right (black: 0, white: 1) with a signal's DFT in *frequency domain* achieves:



i. Low Pass filter
ii. High Pass filter
iii. **Band Pass filter**
iv. Notch filter

c. Multiplication of the mask on the right (black: 0, white: 1) with a signal's DFT in *frequency domain* achieves:



i. Low Pass filter
ii. High Pass filter
iii. Band Pass filter
iv. **Notch filter**

14) **[2+1+1+2+2=8]** Consider a box filter in the *spatial domain.*

a. Convolution of a box filter with a signal in *spatial domain* achieves:
   i. **Low-pass filtering**
   ii. High-pass filtering
   iii. Band-pass filtering

b. The *frequency domain* response of a box filter in spatial domain is a:
   i. Gaussian
   ii. Box
   iii. **Sinc**
   iv. Sine

c. The *spatial domain* response of a box filter in frequency domain is a:
   i. Gaussian
   ii. Box
   iii. **Sinc**
   iv. Sine

d. Which of the following filters is the best low pass filter in *spatial domain*?
   i. **Gaussian**
   ii. Box
   iii. Sinc
   iv. Sine

e. When considering the frequency domain response of the filter in (d), it is superior to others due to:
   i. Its smoothness
   ii. No attenuation of the passed frequencies
   iii. **A good cut-off frequency**

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COLOR [2+10+13=25]

15) **[1+1=2]** Consider two different devices with different 3D color gamuts *A* and *B*.

a. If we apply a gamut transformation, it can create which of the following color artifacts?
   i. **Out of gamut colors creating color blotches**
   ii. Out of gamut colors creating color blurriness
   iii. Gamut compression creating reduction in color contrast and vibrancy

b. If we perform gamut matching, it can create which of the following color artifacts?
   i. Out of gamut colors creating color blotches
   ii. Out of gamut colors creating blurriness
   iii. **Gamut compression creating reduction in color contrast and vibrancy**

16) **[1+3+3+3=10]** Consider a display with 2D color gamut given by chromaticity coordinates of R, G and B as *(0.6,0.4)*, *(0.3, 0.6)* and *(0.2, 0.2)* respectively. The intensity of the R, G and B channels at their maximum is 250, 500 and 250 respectively.

a. The intensity of the white is given by:
   i. 500
   ii. **1000**
   iii. 2000
   iv. 2708.33

b. The white point of the display is given by:
   i. (0.33,0.33)
   ii. (0.3, 0.4)
   iii. **(0.35, 0.45)**
   iv. (0.425, 0.4)

c. The luminance of R, G and B respectively, are given by:
   i. **100, 300, 50**
   ii. 150, 150, 50
   iii. 625, 500, 833.33

~~d. The color matrix of this device (in row-major format) is given by:~~
   ~~*i.* [150 100 0; 150 300 50; 50 50 200]~~
   ~~*ii.* [150 150 50; 100 300 50; 0 50 200]~~
   ~~*iii.* [83.33 83.33 83.33; 166.67 166.67 166.67; 83.33 83.33 83.33]~~
   ~~*iv.* [83.33 166.67 83.33; 83.33 166.67 83.33; 83.33 166.67 83.33]~~

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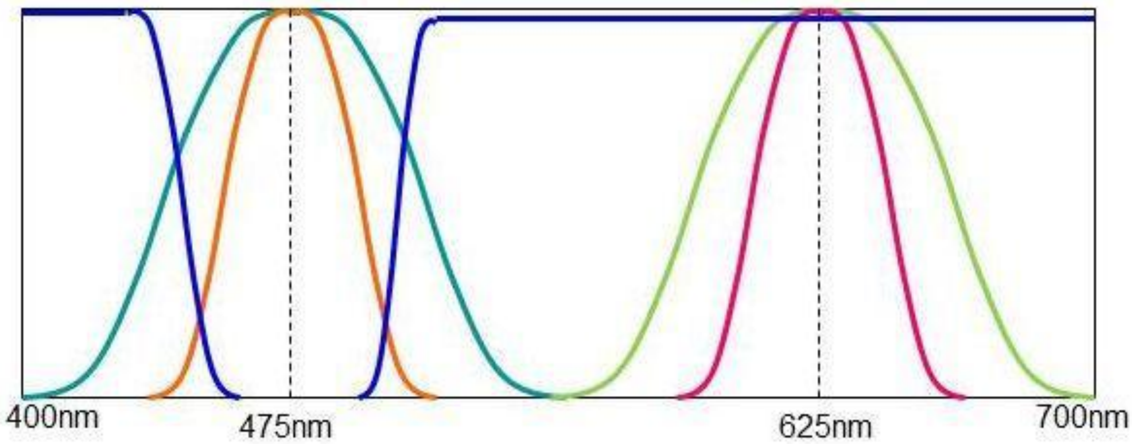
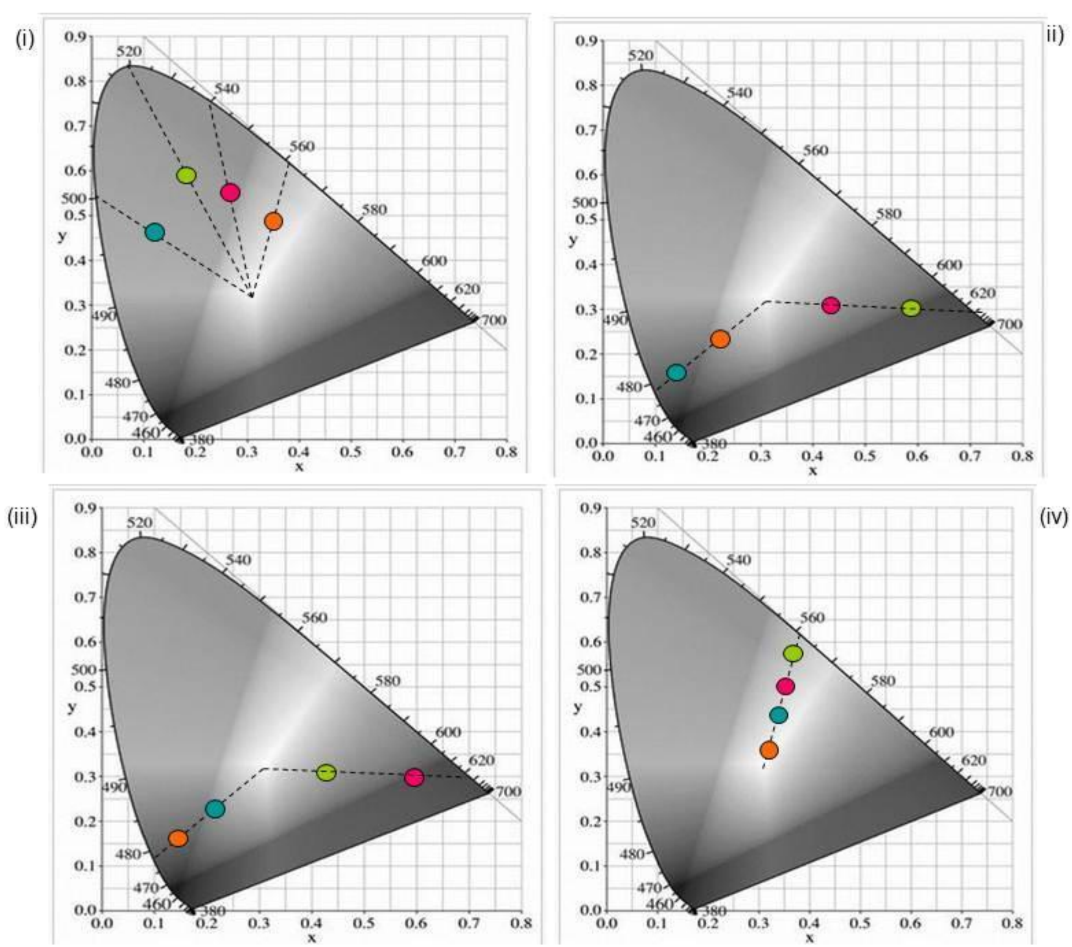
17) [3+1+3+2+2+2=13] Consider the following five spectra. Note that their color in the figure is **not** related to their visible color but used for visualization.



a. Consider the orange, pink, green and cyan spectra. Which one of the following is most accurate representation of position of these spectra on the chromaticity chart? **(iii)**



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b. The dominant wavelength of the orange and cyan spectra is:
   i. **475nm**
   ii. 555nm
   iii. 625nm

c. The intensity *(X+Y+Z)* of the cyan, orange, green and pink spectra are most likely related by the following:
   i. **Orange < Cyan, Pink < Green,**
   ii. Orange < Cyan, Pink < Green, Orange ≈ Pink, Green ≈ Cyan
   iii. Cyan < Orange, Green < Pink
   iv. Cyan < Orange, Green < Pink**,** Green ≈ Orange

d. Consider the blue spectrum. It is most likely the complementary color for the:
   i. Pink spectrum
   ii. Green spectrum
   iii. Orange spectrum
   iv. **Cyan spectrum**

e. Of all the five spectra, which one is the least saturated?
   i. Orange
   ii. Pink
   iii. Green
   iv. Cyan
   v. **Blue**

f. If the chromaticity coordinates of the orange and pink colors are *(0.1, 0.1)* and *(0.6, 0.3)* respectively, the **most likely** chromaticity coordinates of a color formed by their addition is:
   i. (0.15, 0.15)
   ii. (0.6, 0.3)
   iii. **(0.35, 0.2)**
   iv. (0.5, 0.2)