1) C_1 and C_2 are colors with chromaticity coordinates *(0.3, 0.15)* and *(0.6, 0.3)* respectively.

   a. The proportions in which these colors should be mixed to generate a color C_3 of chromaticity coordinates *(0.4, 0.2)* is

      i. *(1/2,1/2)*

      ii. *(1/4,3/4)*

      iii. *(2/3, 1/3)*

      iv. *(1/3, 2/3)*

      2/3(0.3,0.15)+1/3(0.6,0.3) = (0.4, 0.2)

      The other proportions does not yield (0.4,0.2)

   b. If the brightness (X+Y+Z) of C_3 is *90*, the brightness of C_1 and C_2 are

      i. *(45, 45)*

      ii. *(22.5, 67.5)*

      iii. *(60,30)*

      iv. *(30, 60)*

      Intensity is indicator of brightness.

      I1/(I1+I2) = 2/3, I1+I2=90, and therefore I1=60 and I2=30.

   c. The luminance of C_1 and C_2 are

      i. *(6.75, 13.5)*

      ii. *(3.375, 20.25)*

      iii. *(9, 9)*

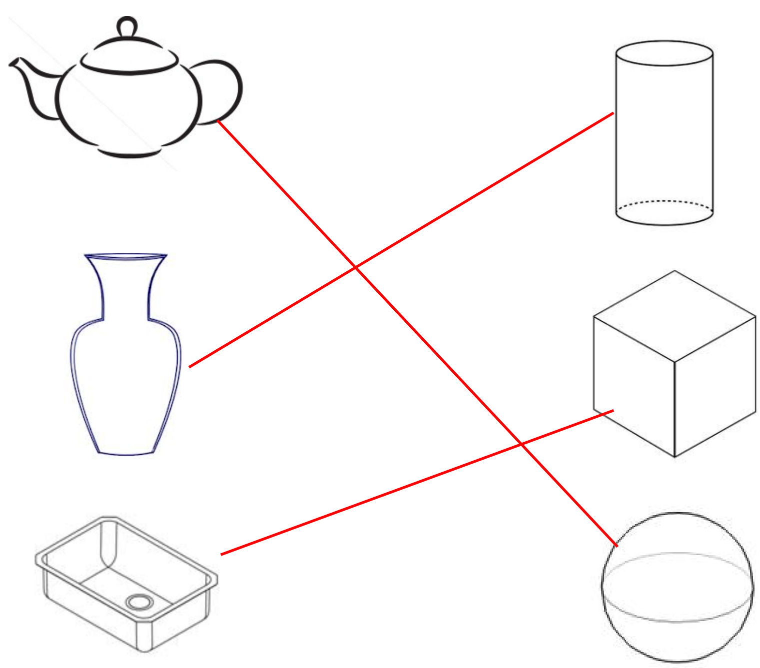
      iv. *(6, 12)*

      Y1/I1=0.15, therefore, Y1= I1*0.15 = 9

      Similarly, Y2=30*0.3 = 9

2) On the left you see models that you would like to texture map. On the right you see the choice of intermediate geometry you have.

   a. Find the matching intermediate geometry that you have to use for each of the objects in the left.



Intermediate shapes should be as close as possible to the object shape to give a good texture mapping.

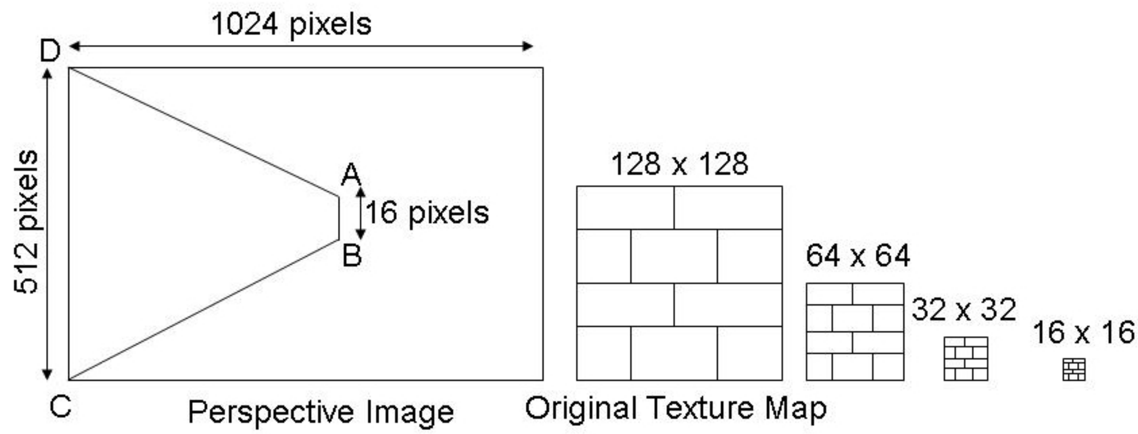
3) Consider the 3x4 camera calibration matrix C. It can be broken into a 3x3 matrix intrinsic parameter matrix K and the 3x4 extrinsic parameter matrix E such that C = KE.

   a. Focal length of the camera will feature in

   i. K
   ii. E
   iii. Both K and E
b. The position of the camera will feature in
   i. K
   ii. E
   iii. Both K and E
c. The orientation of the camera will feature in
   i. K
   ii. E
   iii. Both K and E
d. The pixel size of the camera will feature in
   i. K
   ii. E
   iii. Both K and E
e. The first three columns of E gives the
   i. Focal length of the camera
   ii. Position of the camera
   iii. Orientation of the camera
f. If you know the orientation of the camera, to find its position you need
   i. Just K
   ii. Just E
   iii. Both K and E

4) **[2+2+2=6]** Consider a 1D signal of bandwidth 50Hz. It is amplitude modulated with a carrier wave of frequency of 500Hz for transmission.
   a. This means that in the spatial domain, the signal is
      i. Multiplied with the carrier wave
      ii. Added to the carrier wave
      iii. Convolved with the carrier wave
   b. The bandwidth of the amplitude modulated signal in the frequency domain is
      i. 475-525Hz
      ii. 450-500Hz
      iii. 500-550Hz
      iv. 450-500Hz

      Bandwidth of 50Hz is centered around 500Hz leading to bandwidth of 475-525Hz. Note that by AM, bandwidth is not changed but just shifted to a different location.
   c. The difference in frequency between the carrier signals of different stations should be
      i. 50Hz
      ii. 25Hz
      iii. 100Hz



6) [2+3+1=6] Suppose we have a brick wall that forms the left hand side of a corridor in a maze game as shown in the image below. The image is drawn to scale. This wall is defined in world coordinates by points ABCD, the projection of which are shown in the image. Assume that the brick wall is 16 bricks high.

a. If we assume the brick wall to be 16 bricks high, how many times do we have to repeat the texture in the vertical direction.

- *i.* 2
- *ii.* 4
- *iii.* 6
- *iv.* 8

The texture is 4 bricks high. Therefore, to get 16 bricks high, it has to be repeated 4 times.

b. The level of mipmapped image pyramid on the right that will be used for texture mapping the near end CD is

- *v.* 128x128
- *vi.* 64x64
- *vii.* 32x32
- *viii.* 16x16

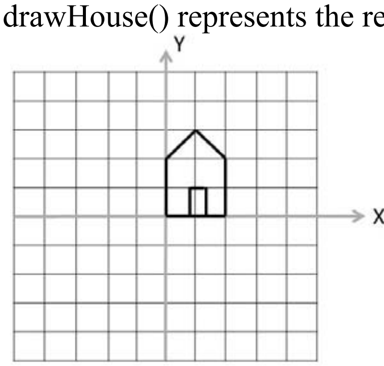
4 times repeated means 512 pixels (128x4). The number of pixels required to adequately sample 512 texels is 1024 pixels. But the number of pixels available in the perspective image is 512. Therefore we need to use a image which when repeated 4 times have 256 texels so that 512 pixels can sample it correctly.

c. To avoid aliasing, the minimum number of pixels each texel should cover are

- *ix.* 1
- *x.* 2
- *xi.* 4
- *xii.* 6

2 pixels in each direction leading to 4. Common mistake is 2.

7) You are given the following model of a house that is transformed by the following OpenGL commands. drawHouse() represents the rendering of the house model.



We write the stack from bottom to top post every instruction.

`glIdentity();` S: I

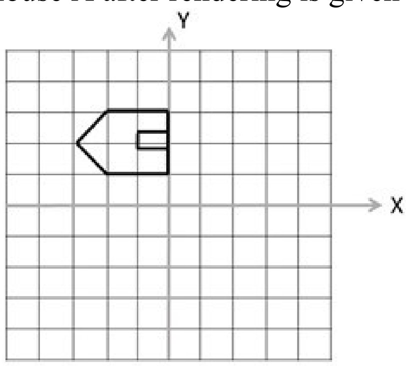
`glTranslate(1, 1, 0);` S: IT(1,1,0)

```
glRotate(90, 0, 0, 1);      S: IT(1,1,0)Rz(90)
glPushMatrix();             S: IT(1,1,0)Rz(90); IT(1,1,0)Rz(90)
glTranslate(1, 0, 0);       S: IT(1,1,0)Rz(90); IT(1,1,0)Rz(90)T(1,0,0)
drawHouse();  // Step for House A
glPopMatrix();              S: IT(1,1,0)Rz(90);
glRotate(45, 0, 0, 1);      S: IT(1,1,0)Rz(90)Rz(45)
glTranslate(-1, 0, 0);      S: IT(1,1,0)Rz(90)Rz(45)T(-1,0,0)
drawHouse();  // Step for House B
```

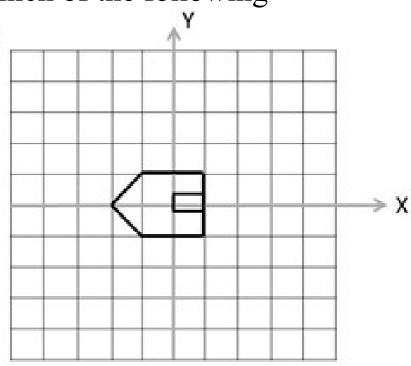
This is the answer for (a) which is (iii)

a. House A after rendering is given by which of the following

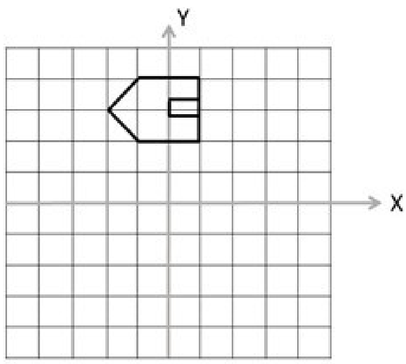
(i)



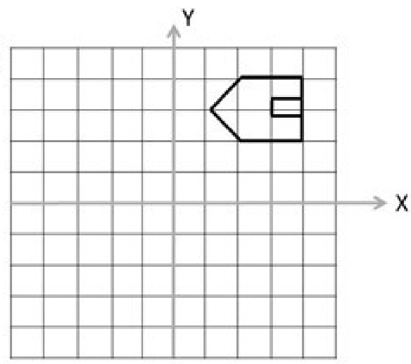
(ii)



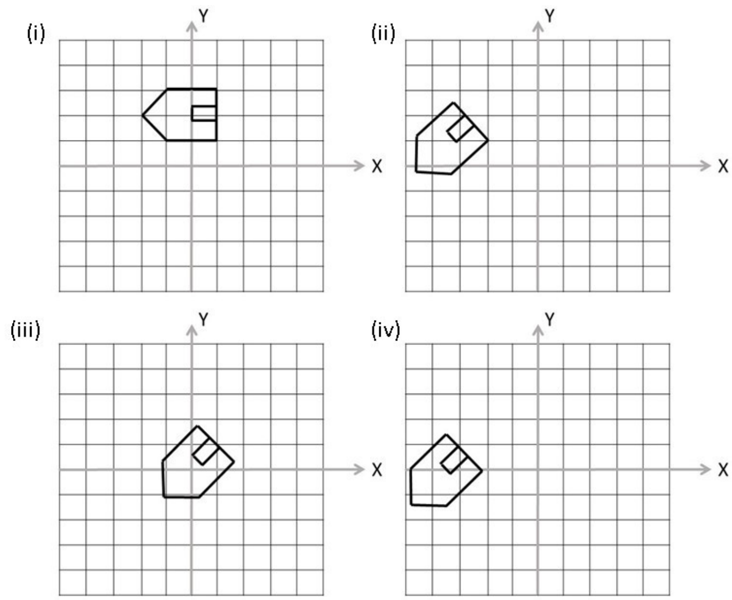
(iii)



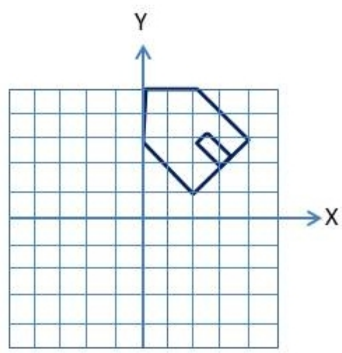
(iv)



b. House B after rendering is given by which of the following. (iii)



c. Which series of OpenGL commands will create the picture below from the original model?



i. glTranslate(2, 1, 0);
glRotate(45, 0, 0, 1);
glScale(1.414, 1.414, 1);

ii. glScale(1.414, 1.414, 1);
glRotate(45, 0, 0, 1);
glTranslate(2, 1, 0);

iii. glTranslate(2, 1, 0);
glScale(1.414, 1.414, 1);
glRotate(45, 0, 0, 1);

iv. glRotate(45, 0, 0, 1);
glScale(1.414, 1.414, 1);
glTranslate(2, 1, 0);

8) Assume two images related by a homography transformation.

a. How many correspondences do you need in the least to recover the homography?

- *i.* Three
- *ii.* Four
- *iii.* Five
- *iv.* Six

8 unknowns in homography matrix. 2 equations per correspondence. Therefore 4 correspondences to solve.

b. Which of the following scenarios result in a homography.

- *i.* The two cameras sharing the same center of projection with different orientation.
- *ii.* The two cameras having the same orientation but are translated with respect to each other.
- *iii.* The two cameras are capturing a 2D planar scene.

9) [2+1=3] Consider two cameras *C1* and *C2* looking at a planar scene. The homography between them is given by $\mathbf{H_{12}}$=[1, 1, 1; 0, 1, 0; 3, 1, 1].

a. Which of the following are the **most likely** corresponding points in *C2* for points (1,0) and (0,1) respectively?

- **i.** (3, 0) and (3,2)
- **ii.** (1/2,0) and (3/2,1)
- **iii.** (1/2,0) and (1,1/2)
- **iv.** (1,0) and (3,0)

Multiply H with point (1,0) in homogeneous coordinate. Therefore, 3x3 H is multiplied by column vectore (1,0,1) to give (2,0,4). Here the last coordinate is 4 and this needs to be normalized --- therefore divide by 4. Exact point is (1/2,0). Similarly we get (1,1/2) for (0,1).

b. Consider a third camera *C3* looking at the same plane and is related by *C2 by* $\mathbf{H_{23}}$. The homography relating camera *C1 to C3,* $\mathbf{H_{13}}$, is given by

- **i.** $\mathbf{H_{12}\, H_{23}}$
- **ii.** $\mathbf{H_{23}\, H_{12}}$

10) Consider two C_1 and C_2 cameras looking at a 3D point P lying on a plane π. Their centers of projection are O_1 and O_2 respectively. The image of P on C_1 and C_2 are p_1 and p_2 respectively.

a. The point where the line O_1O_2 meets the image plane of C1 is called

- *i.* Corresponding point
- *ii.* Epipole
- *iii.* Focus of Expansion

b. Epipolar line is the line formed by the intersection of

- *i.* The plane π with the image plane of C_1 or C_2
- *ii.* The plane O_1O_2P with π
- *iii.* The plane O_1O_2P with the image plane of C_1 or C_2

c. Assuming a fundamental matrix F, Fp_1 gives

- *i.* The point p_2
- *ii.* The equation of the line on which p_2 lies
- *iii.* The affine transformation between the epipolar lines on which p_1 and p_2 lies

d. If both these cameras have parallel image plane, but not coinciding principal axis, the epipoles will be

- *i.* Are at the same position on both the image planes
- *ii.* Are at infinity

iii. Are on π

e. If the principal axis of both these cameras also coincide, then the epipoles

i. Are at the same position on both the image planes

ii. At infinity

iii. On π

11) An image has a linear histogram p(r) = r. We want to transform this image so that its histogram becomes quadratic, $p(z) = z^2$. Assume continuous images.

a. The cumulative histogram of the first image is given by

i. $r^2/2$

ii. r^2 Integration of pdf of r

iii. $r^3/3$

iv. r

b. The cumulative histogram of the second image is

i. $z^2/2$

ii. z^2

iii. $z^3/3$

iv. z

c. The transformation required to achieve histogram matching is given by

i. *z = sqrt(r)*

ii. $r = sqrt(2z^3/3)$

iii. *z = 3/2 r* For matching, answer of (a) and (b) should be equated.

12) Consider a gray world with no ambient and specular lighting (only diffuse lighting). The screen coordinates of a triangle $P_1P_2P_3$ are P_1 = (100,100), P_2 = (300,150), P_3 = (200, 200). The gray values at P_1, P_2 and P_3 are ½, ¾, and ¼ respectively. The light is at infinity and its direction and gray color are (1,1,1) and 1.0 respectively. The coefficient of diffuse reflection is ½. The normals at P_1, P_2 and P_3, are N_1 =(0,0,1), N_2 = (1,0,0) and N_3 = (0,1,0) respectively. (Consider the z coordinates of the three points P_1, P_2, and P_3 to be 0). [**No need to normalize the normal**].

a. The illumination at the three vertices P_1, P_2 and P_3, are given by

i. *(1/2, 3/4, 1/4)* At P1 = kd (N.L) = 1/2(0,0,1).(1,1,1) = 1/2/ Similarly find P2 and P3.

ii. *(1/4, 3/8, 1/8)*

iii. *(1/2,1/2,1/2)*

b. The interpolation coefficients of a point P inside the triangle whose coordinates are (220,160) are given by

i. *(2/5, 1/5, 2/5)* a(100,100)+b(300,150)+ (1-a-b)(200,200) = (220,160)

ii. *(1/4, 3/8, 3/8)* Solving this we get, a=1/5, b=2/5, (1-a-b)=2/5

iii. *(1/5, 2/5, 2/5)*

iv. *(1/4, 1/2, 1/4)*

c. The illumination at P using Gouraud Shading is

i. *15/32*

ii. *1/4*

iii. *9/40*

iv. *1/2*

Interpolate (a) using coefficients found in (b) 1/2*1/5+3/4*2/5+1/4*2/5=1/2

d. The interpolated normal at P is given by 1/5(0,0,1)+2/5(1,0,0)+2/5(0,1,0) = (2/5,2/5,1/5)

   i. *(2/5, 2/5,1/5)*
   ii. *(1/5, 2/5, 2/5)*
   iii. *(1/2, 1/4,1/4)*
   iv. *(3/5, 1/5, 1/5)*

e. The interpolated color at P is given by

   i. *1/5* Color at P1, P2, P3 is given by 1/2, 3/4, 1/4
   ii. *1/2* Interpolate color with (1/5,2/5,2/5) given 1/2
   iii. *1/4*
   iv. *3/8*

f. The illumination at P using Phong Shading is

   i. *15/32*
   ii. *1/4*
   iii. *9/40* N.L at P is (2/5,2/5,1/5).(1,1,1) = 1
   iv. *½* k(N.L) = 1/2.1 = 1/2

Note many answers are 1/2 but we get it in different ways

13) Consider the following matrix that involves a translation, shear and scaling.

[a 0 p x*;* 0 b q y*;* 0 0 1 z*;* 0 0 0 1]

a. The translation parameters in X, Y and Z directions are

   i. (a, b, 0)
   ii. (p,q,0)
   iii. (x,y,z)

b. The scaling parameters in X, Y and Z directions are

   i. (a, b, 1)
   ii. (p,q,1)
   iii. (x,y,z)

c. The shear is a

   i. X-shear
   ii. Y-shear
   iii. Z-shear

d. The parameters of shear are

   i. (p, q)
   ii. (a, b)
   iii. (x, y)

2. Consider two colors *C1=(X1,Y1,Z1)* and *C2=(X2,Y2,Z2)* in the CIE XYZ space. Let their chromaticity coordinates be *(x1,y1)* and *(x2,y2)* respectively.

a. If *C1* is a pure achromatic color, which of the following *are* true.

   i. X1=Y1=Z1
   ii. (x1,y1) = (1/3,1/3)
   iii. Black lies on the ray connecting the origin to *C1* in XYZ space
   iv. White lies on the ray connecting the origin to *C1* in XYZ space

b. If *C2= (50,100,50),* then *(x2,y2)* is given by

   i. (1/2,1/2)
   ii. (1/4,1/2)
   iii. (1/2,1/4) x2 = 50/(50+100+50) = 1/4, similarly y2 = 1/2

c. The dominant wavelength of *C2* is

- *i.* *550nm*
- *ii.* *515nm*
- *iii.* *490nm*
- *iv.* *610nm*

d. To create a color of chromaticity coordinates *(7/24,10/24)*, in what proportions should be *C1* and *C2* be mixed?

- *i.* (1/4,3/4)
- *ii.* (3/10, 7/10)
- *iii.* (1/2,1/2)
- *iv.* (2/5,3/5)

a(1/3,1/3) + (1-a)(1/4.1/2)=(7/24,10/24)

e. The intensity of *C1* required for this mixture is

- *i.* 200
- *ii.* 300
- *iii.* 100
- *iv.* 400

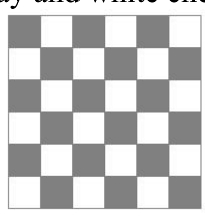
C1 and C2 are used in equal proportion from (d). Intensity of C2 is 200. Therefore, C1's intensity should also be 200.

f. The luminance of *C1* required for this mixture

Y1/200=1/3, Therefore, Y1 = 200/3 = 66.67

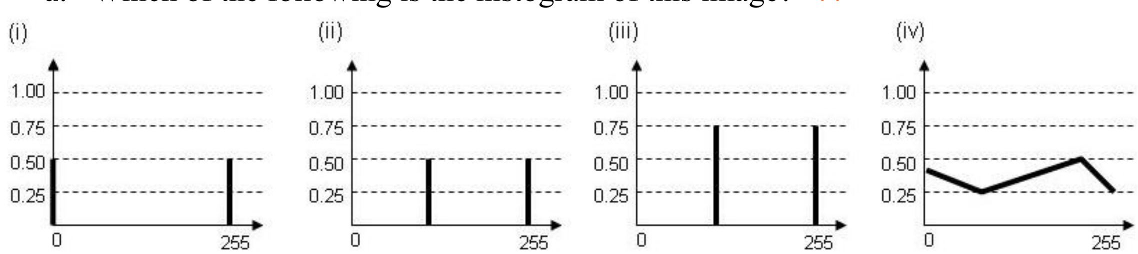
- *i.* 66.67
- *ii.* 100
- *iii.* 33.33
- *iv.* 133.33

3. **[2+2=4]** Consider the following gray and white checkerboard image.

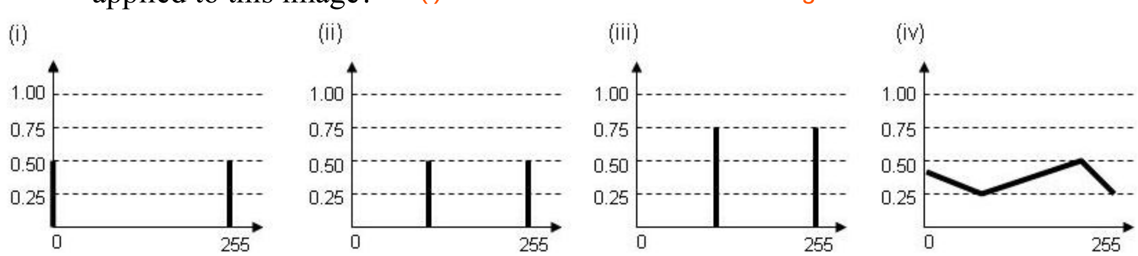


Note that the darker checkers are not black, but are gray.

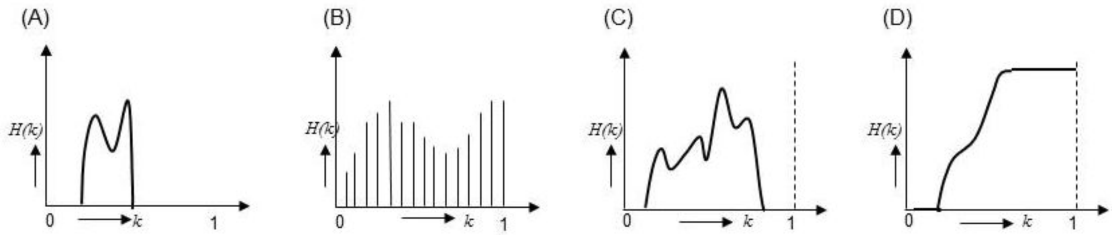
a. Which of the following is the histogram of this image? (ii)



b. What do you expect the histogram to be after global histogram stretching has been applied to this image? (i) -- after stretchin the entire range is used

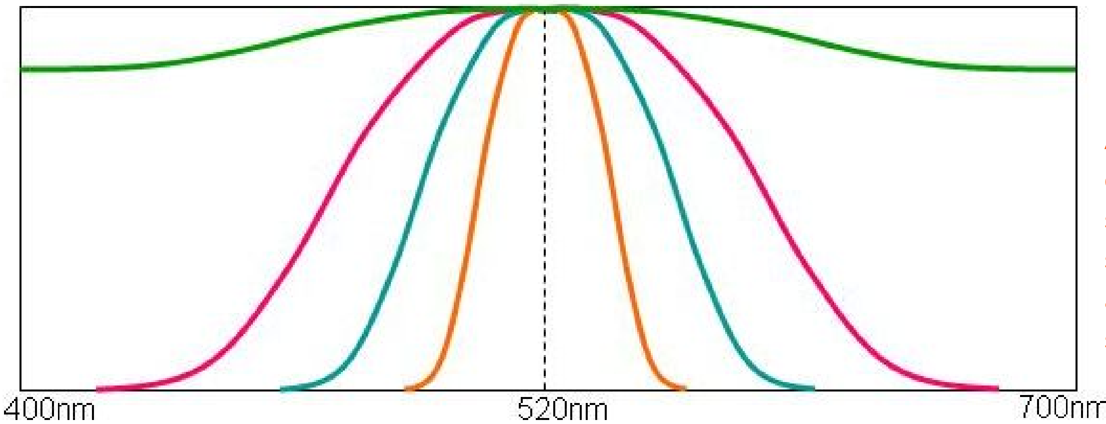


4. [2+2+2+1+1+1=9] Let us consider two images with histograms show in (A) and (C) below.



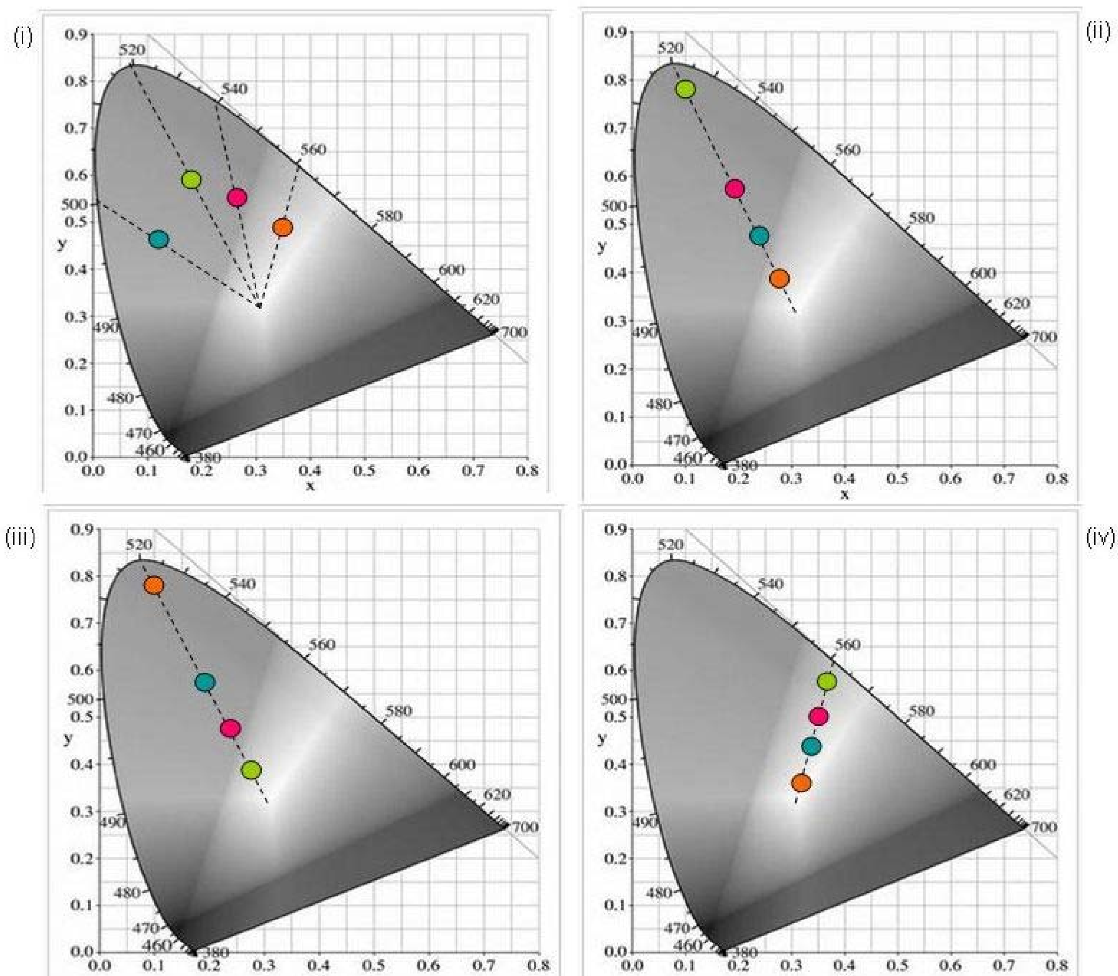
a. Which of the following statements are true?
   i. A has lower contrast than C
   ii. C has lower contrast than A
   iii. Cannot tell if the contrasts of A and C are different
b. If we apply a global histogram stretching to A, the most likely histogram that would result is
   i. A
   ii. B
   iii. C
   iv. D
c. If we take a cumulative sum of the histogram of A, the most likely histogram that would result is
   i. A
   ii. B
   iii. C
   iv. D
d. Global histogram stretching can create the following artifacts
   i. Quantization
   ii. Burn and Dodge
   iii. Rainbow effect
e. This happens since global histogram stretching cannot handle
   i. High color resolution
   ii. Local contrast variation
   iii. Non-linear gamma function
f. This can be alleviated using
   i. Histogram matching
   ii. Adaptive histogram stretching
   iii. Histogram equalization

5. [3+2+2+2=9] Consider the following four spectrums, their color not related to their visible colors, but used for visualization.



All have same hue. But orange has most saturated and then saturatuion gets lower as the spread of the spectrum increases.

a. Which one of the following is most accurate representation of where these spectrums will fall on the chromaticity chart is given by Answer:(iii)



b. The dominant wavelength of all these colors are most likely

- **i.** Same
- **ii.** Entirely different
- **iii.** Clustered together

c. The intensity (X+Y+Z) of these colors are most likely related by the following.

   i. Not related at all
   ii. Orange < Blue < Pink < Green
   iii. Green < Pink < Blue < Orange
   iv. Blue < Pink < Orange < Green

d. The most likely position of these colors in the CIE XYZ 3D space is

   i. On the same ray from the origin
   ii. On four different rays from the origin
   iii. On two different rays from the origin
   iv. On three different rays from the origin

Though hue is same, since saturation is different it gives 4 different rays.

6.