CS_255 (2011-2012)
COMPUTER GRAPHICS 1: IMAGE PROCESSING AND SYNTHESIS
(*Attempt 2 questions out of 3*)

Question 1

(a) Image Processing

Given a 3x3 sub-image of pixels, I_{ij}:

$$I_{ij} = \begin{bmatrix} p_{11}\ p_{12}\ p_{13} \\ p_{21}\ p_{22}\ p_{23} \\ p_{31}\ p_{32}\ p_{33} \end{bmatrix}$$

and a 3×3 filter kernel M_{ij}:

$$M_{ij} = \begin{bmatrix} m_{11}\ m_{12}\ m_{13} \\ m_{21}\ m_{22}\ m_{23} \\ m_{31}\ m_{32}\ m_{33} \end{bmatrix}$$

what is the equation for calculating the new intermediate value at pixel p_{22}?

Given the following 5×5 image (grey-level 0-255 image):

90	100	110	130	140
90	110	120	140	150
110	130	150	150	160
120	150	170	170	180
150	170	180	180	200

and 3x3 filter kernel:

1	1	1
1	-8	1
1	1	1

what are the new intermediate values calculated by applying the filter kernel to the image using the process of cross correlation? Your answer should cover the following items:

- give the intermediate values for all possible pixels,
- indicate with a * those pixels that cannot be operated upon,
- suggest various solutions for dealing with * pixels (pixels that cannot be operated on). **[7 marks]**

[Bookwork, understanding, practical application of topic]

$$p_{22} = \sum_{i=1,j=1}^{3,3} p_{ij} m_{ij}$$

*	*	*	*	*
*	*20*	*60*	*-10*	*
*	*-20*	*-60*	*40*	*
*	*-20*	*-80*	*10*	*
*	*	*	*	*

[5 marks]

=could not be applied. Could reduce size of image, make black, keep old colour, use smaller filters towards image edges, etc.* *[2 marks]***

Part ***a*** *subtotal=****[7 marks]***

(b) State the equation used during the normalisation of an image (e.g. applied to intermediate values after cross correlation).

The following 3x3 array of intermediate values is a result of a cross correlation. Apply the normalisation equation to the array to normalise it back to an image in the range 0 to 255.

135	-165	400
-75	-325	15
-90	205	100

[5 marks]

[Bookwork, understanding, practical application of topic]

Normalisation $P = (I - min) \times \frac{255}{(max-min)}$ ***[1 marks]*** *max=400, min=-325.* ***[1 marks]***

Gives

*	*	*	*	*
*	*161.8*	*56.3*	*255*	*
*	*87.9*	*0*	*119.6*	*
*	*82.7*	*186.4*	*149.5*	*
*	*	*	*	*

rounding is acceptable

[3 marks]

Part ***b*** *subtotal=****[5 marks]***

(c) When applying a 3x3 filter at a pixel, how many multiplications and additions are performed at that pixel? What affect on performance will using a 4x4 or 5x5 filter have? What will occur at the edges of the image when 4x4 or 5x5 filters are used?

[4 marks]

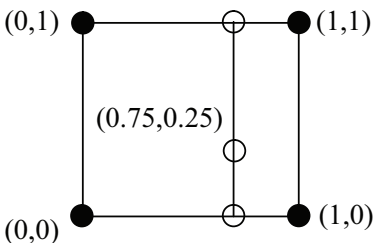
[Bookwork, understanding, practical application of topic]

9 multiplications, 8 additions ***[1 marks]***

A larger filter will take more calculation and therefore be slower - 4×4 *will be 16 multiplications, 15 additions -* 5×5 *will be 25 mults and 24 adds.* ***[1 marks]***

A 4×4 *will have an extra row and column black on the top and side. A* 5×5 *will have 2 rows all the way round black.* ***[2 marks]***

Part ***c*** *subtotal=****[4 marks]***



Point	Intensity
(0, 0)	25
(1,0)	150
(0,1)	50
(1,1)	200

(d) **Interpolation**

Discuss the difference between resizing images using nearest neighbour interpolation and using bilinear interpolation.

Describe linear and bilinear interpolation (giving equations where appropriate) and demonstrate their use to calculate the intensity at positions (0.75, 0) and (0.75, 0.25) in the above square.

[6 marks]

*Describe resizing an image **[2 marks]**, equations for linear interpolation and, bilinear interpolation and application **[2 marks]**. (0.75,0)=118.75, (0.75,1)=162.5, (0.75,0.25)=129.6875 **[2 marks]***

*Part **d** subtotal=**[6 marks]***

(e) **Colour Models** Draw and describe the HSV and RGB colour models. Indicate the parameters controlled by each axis in each model, and the effect of altering each of the parameters.

[3 marks]

[Bookwork and understanding]

*Draw RGB cube and HSV cone, describe altering the HSV or RGB parameters **[3 marks]**.*

*Part **e** subtotal=**[3 marks]***

Question **1** total=**[25 marks]**

Threshold: 5 marks for (a), 2 marks for (b), 2 marks for (c), 2 marks for (d), 2 marks for (e)=13 marks

Question 2

(a) **Aliasing**

(i) What is the cause of noticeable aliasing in images? What is the rate at which signals should be sampled? What name is that frequency known as? **[3 marks]**

(ii) Describe and draw the technique of *Super-sampling* to produce anti-aliased images. **[4 marks]**

(iii) Describe and draw four different sampling strategies. Discuss the merits and demerits of each approach. **[4 marks]**

(iv) Describe and draw the technique of *Adaptive super-sampling* to produce anti-aliased images. **[4 marks]**

*(i) Cause: Regions of high contrast / high frequency - e.g. jump from background colour to object colour. For a signal of frequency f, it should be sampled at 2f. Known as Nyquist rate **[3 marks]**.*

*(ii) For each pixel, many samples are made (for example many rays per pixel are traced). The resulting colours are averaged to create the final pixel colour. For a regular grid of 3 by 3 samples, this approach would take 9 times the amount of work to create the image. It leads to a vast reduction in aliasing, but at the expense of the extra computation. **[4 marks]***

*(iii) Draw the situations for sampling on a regular grid, jittered samples, stochastic sampling and poisson-disk sampling. Computation cost: in order, low, low, low, high. Quality: in order, fourth, second, third, first. Ease of coding: good, good, good, hard. **[4 marks]***

*(iv) PIxel corners are sampled. Until the difference in sample colours is less than a threshold, or we are at a predefined recursive depth, repeat creating more samples at sub-pixel corners. Do this recursively. **[4 marks]***

*Part **a** subtotal=**[15 marks]***

(b) **Descriptions**

Write descriptions (about $\frac{1}{2}$ page) about **three** of the following six topics:

Ray-Sphere intersection equation;
Gamma correction;
Triangle strips;
Maximum intensity projection;
Median filtering algorithm;
Histograms.

[10 marks]

Descriptions

Ray/Sphere intersection: Give the equation
Gamma correction: Raise pixel to the power of gamma. Allows non-linear variation of image brightness. Adapts to log sensitivity of eye.
Triangle strips: n+2 vertices to define n triangles. Each new vertex makes a triangle with the last 2. Draw diagram.
Maximum intensity projection: Rays are sent through volume data to detect the maximum value. This value is mapped onto the grey scale display. Produces x-ray like images.
Median filtering: To remove dust, noise and scratches from images. For a block of nxn pixels, sort the pixels and take the middle value to replace the current value.

Histograms: Created by counting the number of pixels at each intensity level. Usually displayed using a graph. Can be used for other functions such as equalisation to improve contrast.

[10 marks]

*Part **b** subtotal=**[10 marks]***

Question **2** total=**[25 marks]**

Threshold: 8 marks for (a), they should get the reason for aliasing, and most of super-sampling and some of the strategies or the adaptive algorithm. 6 marks for (b), since they have a choice of 3 from 6 they should be able to pick 2 and get good marks. total = 14 marks.

Question 3

(a) **Error Diffusion Dithering**

This is a grey-level image containing pixel values between 0 and 255.

80	90	100	110	110
90	100	120	130	160

(i) What would be the results after *thresholding* to display on a bi-level device? **[2 marks]**

(ii) Calculate the total and average error between the image and the thresholded image. **[2 marks]**

(iii) Demonstrate *standard error-diffusion* on the image. **[3 marks]**

(iv) Calculate the total and average error between the image and the error-diffusion image. **[2 marks]**

(v) How does standard error-diffusion process retain error in the local area? **[1 marks]**

(vi) What is the Floyd-Steinberg method? **[2 marks]**

[Practical application of theory]

(i) Thresholding becomes:

0	0	0	0	0
0	0	0	1	1

[2 marks]

(ii) Original total = 1090. Bi-level image = $2 \times 255 = 510$. *Error=580 too dim. Average=58 too dim.*
[2 marks]

(iii) Error

80	-85	15	125	-20
70	-20	-120	15	-115

Pixels+error

80	170	15	125	235
70	-20	135	15	140

Results

0	255	0	0	255
0	0	255	0	255

[3 marks]

(iv) New dither = $4 \times 255 = 1020$. *Error=70 too dim. Average=7 too dim.*

[2 marks]

(v) It passes the error to the next undrawn pixel and down to the pixel directly below when at the end of the row.

[1 marks]

Floyd Steinberg passes error to 4 undrawn pixels. Error is retained in local area by passing error to neighbourhood, and pixel below at image edges.

[2 marks]

*Part **a** subtotal=**[12 marks]***

(b) **Illumination**

Define each of the following terms:

(i) Surface normal. **[2 marks]**

(ii) Ambient reflection. **[1 marks]**

(iii) Lambertian / Diffuse reflection. **[3 marks]**

(iv) Specular reflection. **[3 marks]**

(Diagrams may be useful in your definition. To achieve full marks for (iii) and (iv), the equations need to be given.

*(i) Surface normal - vector perpendicular to the plane tangential to the surface at the point of measurement (with diagram) **[2 marks]***

*(ii) Ambient reflection - Light assumed to be incident upon a surface even if it is in shadow. **[1 marks]***

*(iii) Lambertian / Diffuse reflection - Light is scattered in all directions equally around the hit point. Governed by the cosine of the angle between the surface normal and vector to the light (calculated via a dot product). **[3 marks]***

*(iv) Specular reflection - Light reflected within a cone close to the mirror angle. Modelled using Phong illumination (again give equation). **[3 marks]***

*Part **b** subtotal=**[9 marks]***

(c) **Bounding Volumes for Ray Tracing**

(i) Explain, with an example scene, why ray tracing can be computationally expensive. (You should include some example calculations). **[2 marks]**

(ii) How can bounding volumes lead to better computational times? (Again use your example to demonstrate by showing some calculations). **[2 marks]**

Bounding Volumes for Ray Tracing

(i) e.g. 1000x1000 pixels and 1000 triangles gives 1 billion intersection calculations. ***[2 marks]***

(ii) Place one sphere around each object in a scene. e.g. assume 10 objects of 100 triangles each. Assume 60 % of rays hit the background. Therefore 600,000 rays are traced against 10 spheres. The remaining are traced against 10 spheres+100 triangles. Equals 50 million intersections. ***[2 marks]***

Question **3** total=**[25 marks]**

Threshold: 8 marks for (a), they should be able to get this largely right if they have revised it. 6 marks for (b). They should be able to define surface normal, ambient and diffuse (maybe without equation). 3 marks for (c). Total=17 marks (but note if they have not revised (a) well, then those students will get substantially less).