CS_255 (2014-2015)
COMPUTER GRAPHICS
(*Attempt 2 questions out of 3*)

These are prepared for the external examiner. The answers are not always good answers, but sometimes are rather brief or contain bullet points to indicate question coverage, or roughly what is required. I have explained this multiple times in the lectures - so most of you should get the message.

Question 1

(a) **Ray Tracing**

(i) Generally, describe the process of ray-object intersections. Specifically, derive the ray-sphere intersection equation. **[4 marks]**

(ii) Define the term *surface normal*. **[2 marks]**

(iii) Describe (with diagrams) how ray tracing manages reflection, refraction and shadows. **[3 marks]**

(iv) Calculate the number of intersections that are required for ray tracing a scene of your own choice. **[2 marks]**

(v) How do bounding volumes speed-up ray tracing? **[2 marks]**

Ray Tracing

(i) 3D ray equation solved with equation of primitive in question. ***[2 marks]*** *Derive the ray-sphere intersection algorithm.* ***[2 marks]***

(ii) Vector perpendicular to tangential plane. ***[2 marks]***

(iii) Show the diagram for each one in question - particularly labelling surface normal, secondary rays and any angles. ***[3 marks]***

(iv) Give an example - e.g. chessboard with 3200 triangles, and 1000x1000 image = 3.2 Billion intersections. ***[2 marks]***

(v) Describe placing a bounding volume around objects and thus a single test against bounding volume can remove the need for tests against all embedded objects if it does not hit the bounding volume. ***[2 marks]***

Part ***a*** *subtotal=****[13 marks]***

(b) **Aliasing**

(i) What is the cause of noticeable aliasing in images? **[2 marks]**

(ii) What is the rate at which signals should be sampled? What name is that frequency known as? **[2 marks]**

(iii) Describe the techniques of *Super-sampling* and *Adaptive Super-sampling* to produce anti-aliased images. **[8 marks]**

(i) Cause: Regions of high contrast / high frequency - e.g. jump from background colour to object colour ***[2 marks]****.*

(ii) For a signal of frequency f, it should be sampled at 2f. Known as Nyquist rate ***[2 marks]****.*

(iii) 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]****. Adaptive super-sampling has 1 per corner of pixel. If they do not differ by more than the threshold, average together to make sample. If they do, create 4 new samples to make 4 sub-pixels, and now recurse the process.* ***[4 marks]****.*

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

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

Question 2

(a) **Cross-correlation**

(i) Given a 3x3 sub-image of pixels, I_{ij}: and a 3×3 filter kernel M_{ij}:

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

what is the equation for calculating the new intermediate value at pixel p_{22}? **[2 marks]**

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

90	110	80	70	80
60	110	100	80	100
70	120	120	100	120
80	130	140	140	160
150	170	180	180	200

and 3x3 filter kernel:

1	3	1
3	9	3
1	3	1

Carry out the process of cross correlation. Your answer should cover the following items:

(ii) What are the intermediate values for all possible pixels? **[3 marks]**

(iii) Indicate with a * those pixels that cannot be operated upon. **[1 marks]**

(iv) Suggest various solutions for dealing with * pixels (pixels that cannot be operated on). **[2 marks]**

(v) What are the maximum and minimum intermediate values? **[1 marks]**

(vi) Give the normalisation equation. **[1 marks]**

(vii) Use the normalisation equation to create the final pixel values. **[2 marks]**

(viii) What differences occur when a 5×5 filter is used? **[2 marks]**

(ix) What difference is made when a colour image needs to be cross correlated? **[1 marks]**

(x) Name some applications of cross correlation. What is a hi-pass filter and what is a low-pass filter and when should they be used? Identify the filter given in the question. **[3 marks]**

[Bookwork, understanding, practical application of topic]

(i)

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

[2 marks]

(ii)

*	*	*	*	*
*	*2520*	*2470*	*2230*	*
*	*2750*	*2920*	*2780*	*
*	*3220*	*3540*	*3620*	*
*	*	*	*	*

[3 marks]

(iii) **=could not be applied.* ***[1 marks]***

(iv) *Could reduce size of image, make black, keep old colour, use smaller filters towards image edges, etc.* ***[2 marks]***

(v) *Max=3620, min=2230* ***[1 marks]***

(vi) *Normalisation equation* $P = (I - min) \times \frac{255}{(max-min)}$ ***[1 marks]***

(vii) *In this case:*

$P = (I - 2230) \times \frac{255}{(3620-2230)}$

Gives

*	*	*	*	*
*	*53.2*	*44.*	*0*	*
*	*95.4*	*126.6*	*100.9*	*
*	*181.6*	*240.3*	*255.*	*
*	*	*	*	*

[2 marks]

(viii) *A* 5×5 *will have 2 rows unknown all the way round.*

Also, increasing the size of the filter will result in the need for more calculation (25 for a 5x5 vs 9 for a 3x3). ***[2 marks]***

(ix) *A colour image will require the above operation to be carried out for each colour channel. The min and max are for all colour channels, and not each individually.* ***[1 marks]***

(x) *Applications: medical imaging and astronomy (low-pass to remove noise). Object recognition, facial recognition (hi-pass to enhance edges).*

This filter is a Gaussian blue. ***[3 marks]***

*Part **a** subtotal=**[18 marks]***

(b) **Median Filtering**

Describe the median filtering algorithm. What are its uses, advantages and disadvantages?

[7 marks]

Median Filtering

Set the filtering size - e.g. 3x3 neighbourhood. For each pixel, examine the neighbourhood. Place all pixel values into an array. Sort the array. Select the median. Use that value as the new value for the pixel. The method is used to remove scratches, dust or noise from images. The size determines the size of scratch, etc. that can be removed. The method is far better than low pass blurring filters as it maintains sharp edges, and can completely remove scratches, noise etc. of the defined size. Larger sizes can result in some rounding of corners, and reduction of the dynamic range.

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

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

Question 3

(a) **Halftoning**

Given the following pattern dithering matrix:

3	7	5
6	1	2
9	4	8

and the following 3x3 grey-level image (with levels from 0 to 255):

100	100	110
110	110	120
120	140	140

Carry out *Pattern Dithering* and *Ordered Dithering* upon the image, namely, for *Pattern Dithering*:

(i) Show the equation for calculating the pattern number. **[2 marks]**

(ii) For pattern dithering, what is the average intensity of the image? **[1 marks]**

(iii) What is the scaled average intensity (between 0 and 1)? **[1 marks]**

(iv) Calculate the pattern number in this case. **[2 marks]**

(v) What pattern will be used to represent this 3x3 image? **[2 marks]**

In addition, for *Ordered Dithering*

(vi) What is the pattern number for each individual pixel? **[3 marks]**

(vii) What pattern will be used to represent this 3x3 image? **[2 marks]**

(i) Pattern number=min(floor(I(n^2+1)), n^2 where n=3 and I=0.4619.* ***[2 marks]***

(ii) Average=1050/9=116.67 ***[1 marks]***

(iii) Normalised (divide by 255)=0.4575 ***[1 marks]***

(iv) Pattern number=4.6 ***[2 marks]***

(v)

#		
	#	#
	#	

(#=pixel turned on) ***[2 marks]***

(vi)

100	3
110	4
120	4
140	5

[3 marks]

	#		
(viii)		#	#
		#	

(vii)

(#=pixel turned on) ***[2 marks]***

*Part **a** subtotal=**[13 marks]***

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

(i) Error diffusion dithering;
(ii) Sampling, quantization and how images are stored (e.g., using Java);
(iii) Maximum intensity projection;
(iv) Ambient, diffuse and specular lighting;
(v) Histograms and histogram equalisation.

[12 marks]

Error diffusion dithering: Set to black or white. Pass error to the next adjacent pixel. Zig-zag through the image. Creates noise between colour changes to give a perceived increase in the colour pallette.

Sampling: Discrete sampling of continuous signal. Quantization: Mapping of continuous value to near discrete value. Java: Store images as 2D arrays where each value is RGB triple (so could also say 3D array).

Maximum intensity projection: Send rays through volume data to detect the maximum intensity along each ray. This is used as the pixel intensity to give an X-ray like image.

Ambient term: Constant lighting added throughout scene. Diffuse term: Dot product of vector to light source and surface normal, light reflects with equal probability over the hemisphere. Specular term: Dot product of the eye vector and ideal reflection vector (and raised to power n). Creates shiny highlight.

Histogram: Count of the number of pixels with each brightness level. Equalisation: Create cumulative distribution function and from that the mapping to map old values to equalised values.

4 marks each for 3 questions.

[12 marks]

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

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