CS_255 (2015-2016)
COMPUTER GRAPHICS
(*Attempt 2 questions out of 3*)

Question 1

(a) **Digital Images**

Define the terms *sampling* and *quantization* in the context of digital images. How are digital images stored in memory? Give some figures for storage sizes for various sized example images.

[6 marks]

Continuous images are sampled at a given resolution to create 2D arrays of pixel intensities (and colours). ***[2 marks]*** *The resulting values may have to be quantized to fit the chosen data type (usually 8 bits per colour channel).* ***[2 marks]*** *Typical storage formats are 8 bits (3R3G2B), 8 bit colour tables, 15/16 bits (5R5G5B), true colour (8R8G8B), or floating point (for HDR).* ***[1 marks]****. Pixels are stored in a 2D array within memory. e.g. true colour will be a 2D array of 24 bit values, a 1Mega pixel image would require 3MBytes uncompressed to store.* ***[1 marks]***

This question is testing foundational knowledge.

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

(b) **Error Diffusion Dithering**

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

130	140	160	180	200
120	130	140	140	140

(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:

[2 marks]

(ii) Original total = 1480. Bi-level image = $9 \times 255 = 2295$*. Error=815 too bright. Average=81.5 too bright.*

[2 marks]

(iii) Error

1	1	1	1	1
0	1	1	1	1

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

Pixels+error

130	15	175	100	300
205	85	210	70	185

Results

[3 marks]

(iv) *New dither* = $6 \times 255 = 1530$. *Error=50 too bright. Average=5 too bright.*

[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]

This question is the practical application of knowledge. Students will have seen the algorithm in lectures and have been taught the theory and motivation, but not implemented it (unless through their own work). They would have seen several examples of the application of the algorithm. This specific problem is unseen.

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

(c) **Histograms**

(i) What is a histogram of an image? What would the histograms of a dark image and a light image look like? **[2 marks]**

(ii) Give the bit of code you would use to compute the histogram. You can assume the array `image[j][i][c]` gives the intensity of colour channel `c` at pixel `(i,j)`. **[2 marks]**

(iii) What does the process of histogram equalisation achieve, and what benefits does it confer? Define cumulative distribution function in your answer, and any equations you know. **[3 marks]**

Histograms

(i) *Count of the number of pixels at each intensity level. Demonstrate a diagram.* ***[2 marks]***

(ii)
```
int[][] h;
h=new int[256][3];
for (j=0; j<height; j++)
   for (i=0; i<width; i++)
      for (c=0; c<3; c++)
         h[image[j][i][c]][c]++;
```

[2 marks]

255	0	255	0	255
255	0	255	0	255

(iii) *Increases the contrast by trying to create a level histogram (using the cumulative distribution function to create a new mapping). Equation from notes.* ***[3 marks]***

This question tests foundational knowledge in (i), technical skills in (ii) and in-depth knowledge of the algorithm in (iii). Students do not need to present the equation for full marks, but it will help a weaker answer obtain full marks.

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

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

Question 2

(a) **Cross-correlation**

(i) 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}? **[2 marks]**

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

180	170	120	0	20
160	160	110	10	40
150	150	120	20	30
190	140	140	20	30
200	170	180	10	40

and 3x3 filter kernel:

1	1	1
1	-8	1
1	1	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)

*	*	*	*	*
*	*-120*	*-130*	*380*	*
*	*-30*	*-210*	*340*	*
*	*180*	*-310*	*410*	*
*	*	*	*	*

[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=410, min=-310* ***[1 marks]***

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

(vii) *In this case:*

$P = (I + 310) \times \frac{255}{(410+310)}$

Gives

*	*	*	*	*
*	*67.3*	*63.8*	*244.4*	*
*	*99.2*	*35.4*	*230.2*	*
*	*173.5*	*0*	*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 an edge detector. ***[3 marks]***

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

This question is the practical application of knowledge. Students will have seen the algorithm in lectures and have been taught the theory and motivation, but not implemented it (unless through their own work). They would have seen several examples of the application of the algorithm. This specific problem is unseen.

(b) **Maximum Intensity Projection**

(i) Describe the data for which the Maximum Intensity Projection (MIP) algorithm is useful. **[2 marks]**

(ii) Describe the MIP algorithm (you can also give pseudo-code). **[3 marks]**

(iii) Why is the MIP algorithm so useful? **[2 marks]**

(i) Volume data - 3D array of data resulting from MR/CT scanners. ***[2 marks]***

(ii) For each pixel, trace a ray through the volume data set taking samples. Find the max sample along the ray, and use its value to colour the pixel according to a map function. ***[3 marks]***

(iii) Gives a 3D X-ray like view of the data. Useful for doctors as they already know how to interpret X-rays. ***[2 marks]***

This question is testing the recollection of an advanced algorithm. This algorithm was set as part of the assignment. Most students will have attempted it, therefore they should be fairly familiar with this part of the course.

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

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

Question 3

(a) **Sampling**

Describe each of the following approaches to sampling **with a diagram and textual description**. Highlight their advantages and/or disadvantages:

(i) Uniform sampling. **[1 marks]**

(ii) Jittered sampling. **[2 marks]**

(iii) Random/stochastic sampling. **[2 marks]**

(iv) Poisson disk sampling. **[2 marks]**

Sampling

(i) *Show regular grid of samples.* ***[1 marks]***
(ii) *Show grid with randomly offset samples.* ***[2 marks]***
(iii) *Show single pixel with multiple randomly placed samples.* ***[2 marks]***
(iv) *Show samples with minimum distance.* ***[2 marks]***

Mainly bookwork from a slightly advanced topic.

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

(b) **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]**

(iii) How does an automatic hierarchical acceleration structure such as a kd-tree or an octree operate? **[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]***
(iii)
(iv) *Automatic methods classify each triangle according to the node it resides in. Division continues until we reach a node with fewer than a predefined number of triangles, or until we reach some depth cut-off. e.g. a kd-tree makes one cut in one dimension and divides the triangles between the 2 children.* ***[2 marks]***

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

Ability to reason and present knowledge from an advanced topic. Mainly lecture/bookwork.

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

(i) Aliasing;
(ii) Object representation;
(iii) Interpolation;
(iv) Gamma correction;
(v) Diffuse/Lambertian shading.

[12 marks]

Descriptions

Aliasing	*They could discuss anything from the topic - e.g., how and why it occurs, Nyquist rate, and solutions such as super-sampling, adaptive supersampling, etc. They should not repeat the sampling patterns from elsewhere in the exam which is not strictly an anti-aliasing technique. They should look at advantages and disadvantages with regard to image quality and speed of each method.*
Object representation	*They could mention explicit and implicit representation, or different types of representation in OpenGL or DirectX. It is also OK to concentrate on one method such as triangular strips and why they are efficient.*
Interpolation	*Interpolation equations and/or the different approaches (nearest neighbour, linear or cubic). Give the relation to graphics in terms of determining colour at a non-integer pixel position.*
Gamma correction	*The gamma correction equation, and the human perception of brightness as a power law.*
Diffuse shading	*The equation for diffuse shading and its relationship to the lighting equation. Or the lighting that occurs when incoming light is reflected with equal probability in all directions.*

[12 marks]

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

The student should sufficiently revise the course so they can compare and contrast differing approaches to a single problem, or should know the equations/algorithms and context for an approach. Most of these are bookwork of slightly advanced topics.

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