CS_217 (2010-2011)

COMPUTER GRAPHICS 1: IMAGE PROCESSING AND SYNTHESIS

(*Attempt 2 questions out of 3*)

Question 1

(a) **Error Diffusion Dithering**

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

120	200	200	180	150
160	180	190	170	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) Why is error-diffusion used, and in general what do the images that have this technique applied, look like? **[2 marks]**

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

[Practical application of theory]

(i) Thresholding becomes:

0	1	1	1	1
1	1	1	1	1

[2 marks]

(ii) Original total = 1710. Bi-level image = $9 \times 255 = 2295$. *Error=585 too bright. Average=58.5 too bright.*

[2 marks]

(iii) Error

120	65	10	-65	85
-75	20	95	-95	-10

Pixels+error

Results

[3 marks]

120	320	265	190	85
180	275	95	160	245

0	255	255	255	0
255	255	0	255	255

(iv) *New dither* = $7 \times 255 = 1785$. *Error=75 too bright. Average=7.5 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]

(vi) *Its used to persuade the viewer that there is higher dynamic range by introducing noise. Close up we see dots of a different colour in what would otherwise have been single colour regions*
[2 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=**[14 marks]***

(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]**

[Understanding of (very) advanced topics]

(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]***

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

(c) **Images in Java**

How are images stored internally? Give some example code that loops through every pixel of an image. How much memory does an image occupy?

[4 marks]

Images in Java

A 3D array (or a 2D array of RGB triples). Each of RGB is a single byte - giving values between 0–255. The memory is width$\times$*height*$\times 3$.

e.g. gamma correction code (but only the 3 loops+the array assignment is needed).

```
for (j=0; j<height; j++)
   for (i=0; i<width; i++)
```

```
for (c=0; c<3; c++)
   image[j][i][c]=
         255.0*Math.pow((image[j][i][c]/255.0),g);
```

[4 marks]

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

Threshold: (a) 8 marks (should get i, iii, vii largely right and some answer for the rest), (b) 4 marks, (c) 2 marks: Total=14 marks

Question 2

(a) **Cross Correlation**

(i) Given a 3x3 sub-image of pixels:

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

and a 3×3 filter kernel:

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

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

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

$$\begin{bmatrix} 90 & 100 & 110 & 130 & 140 \\ 90 & 110 & 120 & 140 & 150 \\ 110 & 130 & 150 & 150 & 160 \\ 120 & 150 & 170 & 170 & 180 \\ 150 & 170 & 180 & 180 & 200 \end{bmatrix}$$

and 3x3 filter kernel:

1	3	1
3	9	3
1	3	1

give the intermediate values for all possible pixels when applying the filter kernel to the image using the process of cross correlation. **[3 marks]**

(iii) What choices could be made at the pixels the filter cannot be operated on. **[2 marks]**

(iv) What are the maximum and minimum intermediate values. **[1 marks]**

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

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

(vii) What differences occur when a 4×4 filter is used, and when a 5×5 filter is used? **[2 marks]**

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

(ix) 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)

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

[2 marks]

(ii)

*	*	*	*	*
*	*2770*	*3120*	*3470*	*
*	*3230*	*3630*	*3830*	*
*	*3710*	*4110*	*4260*	*
*	*	*	*	*

[3 marks]

(iii) **=could not be applied. Could reduce size of image, make black, keep old colour, use nearest known neighbour's colour, use smaller filters at the image edges.* ***[2 marks]***

(iv) *max=4260, min=2770.* ***[1 marks]***

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

(vi) *In this case:*

$P = (I - 2270) \times \frac{255}{(4260-2770)}$

Gives

*	*	*	*	*
*	*0*	*59.9*	*119.8*	*
*	*78.7*	*147.2*	*181.4*	*
*	*160.9*	*229.3*	*255.*	*
*	*	*	*	*

[2 marks]

(vii) *A* 4×4 *will have an extra row and column unknown on the top and one side (or bottom and one side). 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. ***[2 marks]***

(viii) *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]***

(ix) *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=**[21 marks]***

(b) **Histogram**

(i) How is a histogram computed for an image and what does it represent? **[2 marks]**

(ii) What effect does uniformly brightening or darkening an image have on the histogram? **[2 marks]**

(iii) What is the *cumulative distribution function*? **[2 marks]**

(iv) Describe the procedure for *histogram equalisation* and indicate the situation when it should be used and the effect it produces. **[2 marks]**

[Understanding first part, application second part]

(i) *Created by counting the number of pixels at each intensity level, and represents the distribution of intensity throughout the image. Could also give some lines of code, but not required.* ***[2 marks]***

(ii) *Brighter, histogram gathers to right. Dimmer, histogram gathers to left.* ***[2 marks]***

(iii) *t(f) = The total amount of pixels that have a value up to and including f.* ***[2 marks]***

(iv) *Histogram equalisation is used to increase contrast by distributing the available intensity levels better throughout the image. The CDF is used to create a mapping from original values to new values.*

[2 marks]

*Part **b** subtotal=**[8 marks]***

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

Threshold: (a) 8 marks (should get i, ii, iii, ix largely right), (b) 5 (should get i, ii correct, and describe the effect in iv) = 13 total

Question 3

(a) **Object Representation**

Define each of the following terms, also giving their advantages/disadvantages:

(i) Triangle list **[2 marks]**

(ii) Triangle strip **[2 marks]**

(iii) Pointers to vertex list **[2 marks]**

(iv) Implicit representation **[2 marks]**

(i) For each triangle store 3 x 3D points representing the spatial location of each vertex. ***[2 marks]***
(ii) For n triangles, store n+2 points so that the points k, k+1, k+2 give the kth triangle. k takes all values between 1 and n. ***[2 marks]***
(iii) Store a list of 3D points. For each triangle, store the 3 pointers to the vertices that make it. ***[2 marks]***
(iv) An object is described using an equation. ***[2 marks]***

Part ***a*** *subtotal=****[8 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) Discuss a hierarchy of bounding volumes constructed manually. **[2 marks]**

(iv) How does an automatic hierarchical acceleration structure such as a kd-tree or an octree operate? How does it accelerate ray-tracing? **[4 marks]**

Ray Tracing

(i) View plane - rays passing through centre of projection (perspective model) or in parallel (orthographic)
(ii) Primary rays hitting a surface, then reflecting as secondary rays.
(iii) Primary rays hitting a surface, then refracting through a transparent object.
(iv) Primary rays hitting a surface, then secondary rays being used to determine light visibility (shadow)
(v) Recursive ray tracing: secondary rays can interact just like primary (i.e. further reflection and refraction)
(vi) Derive ray/sphere intersection equation by substituting the equation of a ray in the equation of sphere.

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

(c) **Descriptions**

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

Illumination (ambient, diffuse/Lambertian, specular);
Gamma correction;
Adaptive supersampling;
Linear and bilinear interpolation.
Jittered sampling, random/stochastic sampling and Poisson disk sampling.
Nyquist rate, quantization and sampling for discrete images.

[7 marks]

Descriptions

Illumination (ambient, diffuse/Lambertian, specular): Give the simple rendering equation. Talk about light colour and object colour. Talk about the angle, surface normal and angle of incidence.
Gamma correction: Raise pixel to the power of gamma. Allows non-linear variation of image brightness. Adapts to log sensitivity of eye.
Adaptive supersampling: Sample once per pixel corner. Where these differ by more than predefined threshold, take more samples at sub-pixels, and continue as a recursive algorithm.
Linear and bilinear interpolation: Define equation for linear interpolation. Demonstrate this applied to 2D using bilinear interpolation. Maybe mention use for image resizing.
Jittered sampling, random/stochastic sampling and Poisson disk sampling: Jittered - one sample per sub-pixel, but randomly offset from centre (but still in sub-pixel, fast to compute). Random - random samples over pixel (could lead to undersampled areas, fast to compute). Poisson-disk - best kind of sampling, but O(logn) to generate each sample (other methods O(1).
Nyquist rate, quantization and sampling for discrete images: Sampling frequency (2f) needed to reconstruct a signal of frequency f. Sample at a finite number of positions along signal (e.g. regular sampling for digitising images). Quantization of signal to available bit resolution.

[7 marks]

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

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

Threshold: (a) 5 should get something on the first 3, (b) 4 should get the concepts of bounding volumes and expense of intersections across, (c) 4 should be able to chose something they are good at = 13 total