CS_217 (2013-2014)
COMPUTER GRAPHICS
(*Attempt 2 questions out of 3*)

Question 1

(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):

50	60	65	70	80
60	110	120	140	150
60	130	150	150	160
55	115	150	170	180
150	170	180	180	200

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)

*	*	*	*	*
*	*-185*	*-85*	*-175*	*
*	*-220*	*-115*	*20*	*
*	*125*	*45*	*-10*	*
*	*	*	*	*

[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=125, min=-220* ***[1 marks]***

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

(vii) *In this case:*

$P = (I + 220) \times \frac{255}{(125+220)}$

Gives

*	*	*	*	*
*	*25.9*	*99.8*	*33.3*	*
*	*0*	*77.6*	*177.4*	*
*	*255.*	*195.9*	*155.2*	*
*	*	*	*	*

[2 marks]

(viii) *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]***

(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]***

(b) **Denoising images**

Compare and contrast median filtering and Gaussian smoothing for denoising images. What are the advantages and disadvantages of these approaches? Describe exactly how the median filtering algorithm operates. What happens if we use a larger kernel size? What are common sources of noise in images, and what is the effect of these algorithms on the noise present in such images?

[7 marks]

Centre kernel over the pixel. Sort values. Pick median. ***[2 marks]*** *Larger kernel results in loss of corners. Answer may also state colour quantization. Could also include larger filters remove larger noise or wider scratches.* ***[2 marks]*** *Transmission errors, scans of analogue sources with scratches or dust* ***[1 marks]*** *Blur filters (Gaussian smoothing) will blur the whole image including edges. Also they do not completely remove scratches, noise etc. Median filter of appropriate size will remove scratches and noise up to that size* ***[2 marks]***

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

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

Question 2

(a) **Ray Tracing**

Describe the process of recursive ray tracing. Include diagrams and examples to help with your description. Show the difference between orthographic and perspective rays by drawing a diagram with the view plane, centre of projection, pixels and rays labelled. Derive the ray/sphere intersection equation. Give an example of why naive ray tracing is regarded as a computationally costly algorithm. **[14 marks]**

Ray Tracing

(i) View plane - rays passing through centre of projection (perspective model) or in parallel (orthographic) ***[2 marks]***
(ii) Primary rays hitting a surface, then reflecting as secondary rays. ***[2 marks]***
(iii) Primary rays hitting a surface, then refracting through a transparent object. ***[2 marks]***
(iv) Primary rays hitting a surface, then secondary rays being used to determine light visibility (shadow) ***[2 marks]***
(v) Recursive ray tracing: secondary rays can interact just like primary (i.e. further reflection and refraction) ***[2 marks]***
(vi) Derive ray/sphere intersection equation by substituting the equation of a ray in the equation of sphere. ***[2 marks]***
(vii) Some calculations on number of pixels and objects to show expense ***[2 marks]***

*Part **a** subtotal=**[14 marks]***

(b) **Illumination**

Define each of the following terms:

(i) Surface normal. **[2 marks]**
(ii) Direct versus indirect illumination and the role of ambient illumination. **[2 marks]**
(iii) Lambertian / Diffuse reflection. **[2 marks]**
(iv) Specular reflection. **[2 marks]**
(v) The equation for the simple reflection model. **[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. Example of indirect - light source in shadow, but bouncing off mirror to give illumnation. ***[2 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). ***[2 marks]***
(iv) Specular reflection - Light reflected within a cone close to the mirror angle. Modelled using Phong illumination (again give equation). ***[2 marks]***
(v) Give complete equation from notes ***[3 marks]***

*Part **b** subtotal=**[11 marks]***

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

Question 3

(a) **Graphics Code**

What does each of the following code fragments do (assuming they are part of a larger program)?

(i)
```
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);
```
[2 marks]

(ii)
```
grey[j][i]=grey[j][i]+error
if (grey[j][i]<threshold) {
   bw[j][i]=0
   error=grey[j][i]
}
else {
   bw[j][i]=max_intensity
   error=grey[j][i]-max_intensity
}
```
[2 marks]

(iii) What is a histogram? **[2 marks]**

(iv) In a similar format to above, give a code fragment for calculating a histogram. **[2 marks]**

(i) Gamma correction ***[2 marks]***

(ii) The operation carried out at every pixel during error diffusion ***[2 marks]***

(iii) Count of the number of elements at each value - e.g. number of blue pixes at each 0-255 intensity level. ***[2 marks]***

(iv)
```
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]

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

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

(i) Error diffusion dithering;
(ii) Bounding volumes and trees for ray tracing;
(iii) Maximum intensity projection;
(iv) Aliasing and anti-aliasing;
(v) Image resizing using bilinear interpolation.

[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.

Bounding volumes and trees for ray tracing: Use tight fitting single primitive bounding volumes around more complex models with many primitives. Only test primitives that are in hit bounding volumes. Greatly accelerates ray tracing. Can generalise to octrees (or kdtrees) where the data structure is built to organise the underlying primitives, then queried during ray intersection.

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.

Aliasing and anti-aliasing: The problem of sampling below the Nyquist frequency creates blocky artifacts in images. Can be resolved by over-sampling (or adaptively over-sampling) and then averaging the derived intensities to result in one pixel value.

Image resizing using bilinear interpolation: Give the equation for linear and bilinear interpolation. Suggest the problem with image resizing (a non-integer ratio) is that samples must be taken from between existing samples. Therefore interpolation is used.

4 marks each for 3 questions.

[12 marks]

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

(c) **Triangular Strips** Draw an example of a triangular strip. Describe your diagram. What advantages does the triangular strip representation offer in terms of space and rendering (and why?).

[5 marks]

[Bookwork / understanding]

*Draw a diagram of a triangular strip **[1 marks]**. Describe it (triangle between vertices 1, 2, 3, 2nd triangle = vertices 2, 3, 4, etc). **[2 marks]**. n+2 vertices to represent n triangles is very efficient, some edge data can be shared (e.g. normals) during rendering (e.g. hardware rendering) **[2 marks]***

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

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