

Computer Graphics and Computer Vision (103251/01)

Section A Computer Graphics, Dr Nick Holliman**Question 1**

This question is about light and colour in digital imaging.

- (a) Describe, using a diagram if appropriate, how the eye processes light and detects colour. **[5 Marks]**
- (b) Define the *colour gamut* of a display or hard copy device. Describe the CIE chromaticity diagram and explain why it is useful for comparing device colour gamuts. **[5 Marks]**
- (c) Explain the RGB and HLS colour models, discuss appropriate uses of these two colour models in computer graphics and digital imaging. **[5 Marks]**
- (d) Assuming each pixel on a display is a square and ignoring the fact that it is made up from three colour components, calculate:
 - i. The minimum visible pixel size assuming:
the viewing distance is 330mm and
the minimum visual angle is $\frac{1}{60}$ of a degree. **[3 Marks]**
 - ii. Assuming a modern LCD display has a resolution of 1024x768 pixels and a pixel size of 0.3mm what resolution would the same screen have if it was manufactured with pixels of the size you have calculated in part (i)? **[2 Marks]**

Question 2

This question is about lit scenes in Java3D and the underlying lighting model.

- (a) Sketch the content branch of a scene graph for Java3D containing the components required to produce a simple scene with ambient and point source lighting in it. Discuss the role of each component and any supporting components they require to function correctly.

[7 Marks]

- (b) The equation below is the basis of the lighting model in Java 3D.

$$I = (I_e) + (L_a * K_a) + (L_p * (N.L) * K_d) + (L_p * (R.E)^n * K_s) \quad (1)$$

- i. Define the role of each parameter in this equation, use a diagram of the geometry of this lighting model at a vertex as part of your explanation. **[9 Marks]**
- ii. Describe how the ambient, diffuse and specular reflection of light are simulated by this model. **[4 Marks]**

Question 3

This question is about the use of 3D homogeneous coordinates and transformation matrices in the graphics pipeline.

Clearly give details of all working and assumptions in your answer.

- (a) Calculate the number of floating point operations required to undertake the following computations. Assume that scalar multiplication and addition both count as single operations.
 - i. Transform a single vertex represented in homogenous coordinates by a single transformation matrix. **[4 Marks]**
 - ii. Multiply two transformation matrices together. **[2 Marks]**
- (b) Consider two objects, a triangle and an object containing 100 million vertices. A series of three transformations are to be applied to each object, for example they may be translated to the origin, rotated around the origin and translated back to their original position.

For each object calculate the following:

- i. How many floating point operations are required if the transformation matrices are applied individually. **[4 Marks]**
 - ii. How many floating point operations are required if the transformation matrices are multiplied together. **[2 Marks]**
- (c) Referring to the results in section b) discuss the benefits of using homogeneous coordinates. Comment on the computational complexity of applying transformation matrices individually compared to applying them as a single combined matrix, which approach would you adopt in designing a high performance graphics pipeline ? **[8 Marks]**

Question 4

This question is about the simulation of global illumination using the ray tracing algorithm.

- (a) Describe the recursive ray tracing algorithm. Use a diagram to illustrate both the different types of rays generated and the key geometric features required in ray tracing.

[10 Marks]

- (b) You are given a recursive ray tracing system and told it is running slowly because it uses no acceleration methods for visibility calculations. Describe how the system's performance could be improved by using spatial partitioning techniques, compare and contrast the benefits of regular and adaptive spatial partitions.

[6 Marks]

- (c) Classical ray tracing algorithms take account of point light sources only, explain how the classical algorithm can be extended to account for area light sources.

[4 Marks]

Section B Computer Vision, Dr Andrew Hunter**Question 5**

- (a) List the five stages in connected components analysis, and briefly describe them in no more than one or two sentences each. [5 Marks]
- (b) Compare mean and median filtering, discussing the type of noise for which each is suitable. [5 Marks]
- (c) In convolution, what is a *separable kernel*, and how can separability be exploited? [4 Marks]
- (d) Describe how the operations of convolution and correlation can be used for template matching, and discuss the relationship between these operations. [6 Marks]

Question 6

- (a) Describe the circumstances under which dilation is *extensive*. [3 Marks]
- (b) State how the structuring element N_4 below can be used for speckle removal in mathematical morphology. [3 Marks]

$$N_4 = \begin{array}{|c|c|c|} \hline & \bullet & \\ \hline \bullet & + & \bullet \\ \hline & \bullet & \\ \hline \end{array}$$

- (c) Draw two diagrams showing the results of, i) dilating I with the structuring element D , and ii) eroding the image I with the structuring element E , where \bullet indicates foreground pixels and members of the structuring element, and $+$ indicates the origin of the structuring element. [4 Marks]

$$I = \begin{array}{|c|c|c|c|c|} \hline \bullet & & & & \\ \hline \bullet & & & & \\ \hline \bullet & \bullet & & \bullet & \\ \hline & & & \bullet & \bullet \\ \hline \end{array} \quad D = \begin{array}{|c|c|} \hline \bullet & \bullet \\ \hline & \\ \hline & \bullet \\ \hline \end{array} \quad E = \begin{array}{|c|c|} \hline \bullet & + \\ \hline & \bullet \\ \hline \end{array}$$

- (d) You have acquired a piece of specialized hardware that performs very fast dilation, and you are provided with an API (Application Programming Interface) that allows you to perform dilation by passing an image and a kernel to a special function. Unfortunately, the hardware and API do not provide an erosion function. Explain how you could exploit the API to provide a fast erosion function. [5 Marks]
- (e) Define morphological *opening*, explain its effect upon a binary image, and specify one use for it. [5 Marks]

Question 7

- (a) Define the *co-occurrence matrix*, used in texture recognition. **[2 Marks]**
- (b) You are required to provide part of a system that detects cars moving along a road. Other staff are responsible for capturing the images, and processing them so that you receive an edge-detected side-view taken from a standard distance; the picture is scaled so that there is unlikely to be more than one car in view. Describe the Generalized Hough transform, and explain how you could use it to locate the car within the image. **[8 Marks]**
- (c) Explain how Otsu's method is used in thresholding, and outline any assumptions underlying the technique. **[4 Marks]**
- (d) In an object recognition task, it is often relatively easy to extract a large number of features (including shape, colour and texture features). Given a significant library of sample images, outline how feature selection and statistical pattern recognition can be used to develop a method of distinguishing object classes based on extracted features. **[6 Marks]**

Question 8

- (a) State the formula for the Fourier transform, $\mathfrak{F}(u, v)$, of an image function, $f(x, y)$ [2 Marks]
- (b) In the context of Fourier analysis, what is the *convolution theorem*, and how can it be exploited? [6 Marks]
- (c) Images have been acquired from a satellite camera. Due to hardware problems the images are corrupted with wave-like patterns that repeat approximately every 30 pixels horizontally and 10 pixels vertically. Explain how frequency-domain filtering can be used to remove this noise. [6 Marks]
- (d) Compare and contrast ideal and Gaussian filters in the frequency domain. [6 Marks]