IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

EXAMINATIONS 2019

BEng Honours Degree in Computing Part III
BEng Honours Degree in Electronic and Information Engineering Part III
MEng Honours Degree in Electronic and Information Engineering Part III
MEng Honours Degree in Mathematics and Computer Science Part IV
BEng Honours Degree in Mathematics and Computer Science Part III
MEng Honours Degree in Mathematics and Computer Science Part III
MEng Honours Degrees in Computing Part III
MSc in Computing Science
MSc in Computing Science (Specialist)
for Internal Students of the Imperial College of Science, Technology and Medicine

This paper is also taken for the relevant examinations for the Associateship of the City and Guilds of London Institute

PAPER C317

GRAPHICS

Thursday 21st March 2019, 10:00
Duration: 120 minutes

Answer THREE questions

Paper contains 4 questions
Calculators required

1 Transformations

a Name the type of transformation that is defined by the following 4×4 matrices. Please write in your answer book e.g. i) $\mathbf{M}_1$ = "identity transformation", ii) $\mathbf{M}_2$ = ...

i) $$\mathbf{M}_1 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

ii) $$\mathbf{M}_2 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

iii) $$\mathbf{M}_3 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

iv) $$\mathbf{M}_4 = \begin{pmatrix} 5 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

v) $$\mathbf{M}_5 = \begin{pmatrix} 0.70710689672 & 0 & 0.70710666564 & 0 \\ 0 & 1 & 0 & 0 \\ -0.70710666564 & 0 & 0.70710689672 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

vi) $$\mathbf{M}_6 = \begin{pmatrix} 1 & 4 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

vii) $$\mathbf{M}_7 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

viii) $$\mathbf{M}_8 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -10 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

ix) Which of the matrices i)-vii) are invertible? Briefly outline your intuition about why some of these matrices are non-invertible.

b Suppose we would like to mirror an object across a plane $ax + by + cz + d = 0$. In a specific case the plane is defined by $a = 1, b = 0, c = 0, d = y_0$. Write down the transformation matrix which achieves this mirror reflection for this specific case.

c A 2D affine transformation **M** maps the shape on the left in Figure 1 to the shape on the right in Figure 1. Specify the 3×3 homogeneous transformation matrix that represent **M** using integer values.

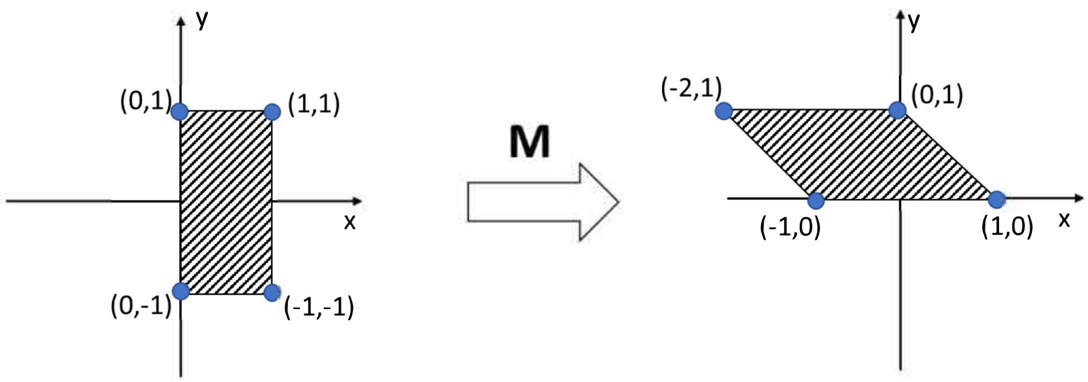

Fig. 1: Model the homogeneous transformation matrix for this 2D transformation.

d Suppose we look at a unit cube from the point $(0,0,4)$ in the direction $(0,0,1)$. The unit cube has corners at (0, 0, 0), (0, 0, 1), (0, 1, 0), (1, 0, 0), (0, 1, 1), (1, 1, 0), (1, 0, 1), (1, 1, 1). The scene is to be drawn in perspective projection and the plane of projection is z = 2.

i) What homogeneous transformation matrix achieves this projection?

ii) Sketch what the picture will look like. You may assume there are no clipping planes.

The four parts carry, respectively, 40%, 20%, 20%, and 20% of the marks.

2 Illumination and shading

a In Figure 2, the eye (view point) is located on the right, a plane (line) along the bottom (y = 0), and a point light source towards the left. The light is at location $(-4, 3)$ and the view point is at $(2, 2)$. The normal vector of the plane is $(0, 1)$

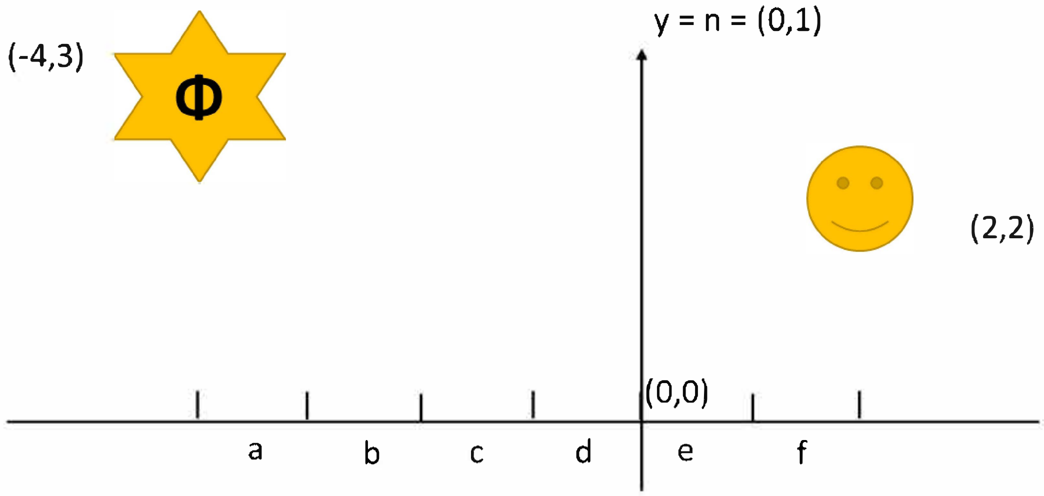

Fig. 2: light is at location $(-4, 3)$ and the view point is at $(2, 2)$

i) Assume that the plane/line has only a specular material component and that flat shading is used for segments [a-f]. Furthermore, assume that the specular coefficient q is large and the intensity of the light does NOT attenuate with distance. Identify the segment [a-f] position at which the plane/line will appear brightest to the viewer when considering **only the specular component**. Justify your answer

ii) Assume instead that the plane/line only has a diffuse material component. Again, you can assume that flat shading is used for segments [a-f] and that the intensity of the light does NOT attenuate with distance. Identify the segment [a-f] at which the plane/line will appear brightest to the viewer when considering **only the diffuse component**. Justify your answer

iii) What is the location of the brightest **specular** point on the plane/line in the scene in Figure 2? You can assume that two vectors are parallel if they align by 99%, i.e. less than 1° degree deviation is acceptable.

iv) What is the exact location of the brightest **diffuse** point on the plane/line in the scene in Figure 2?

b You are given a rectangle $ABCD$ in screen space. Each vertex of the rectangle has an RGB colour, to be used for Gouraud shading:

Vertex	Screen Coordinates	(R,G,B) Colour
A	(0,1)	(128,128,0)
B	(8,1)	(250,0,0)
C	(8,6)	(250,0,250)
D	(0,6)	(0,0,250)

i) Express point E = (6, 1) as an affine combination of points A and B.

ii) Express point F = (1, 6) as an affine combination of points C and D.

iii) Express point G = (4, 4) as an affine combination of points E and F

iv) If Gouraud shading is used at point G, what should its RGB colour be at points E, F and G?

v) Which part of the GLSL shading pipeline would be most suited to implement Gouraud shading? State the common name for this shader in the pipeline.

The two parts carry, respectively, 65% and 35% of the marks.

3 Raytracing

a The table below defines six connected triangles in screen space that form a patch of a polyhedra. The viewing position is at $(0,0,0)$.

vertex	coordinates	triangle	connectivity
A	$(2,1,-3)$	$T1$	(A,B,G)
B	$(7,0,-4)$	$T2$	(B,F,G)
C	$(3,9,-5)$	$T3$	(F,E,G)
D	$(10,8,-6)$	$T4$	(E,D,G)
E	$(10,5,-7)$	$T5$	(G,D,C)
F	$(10,3,-8)$	$T6$	(G,C,A)
G	$(5,5,-2)$		

i) Draw a sketch of this scene when projected on a plane defined by its normal $(0,0,-1)$ and a point $(0,0,-1)$. You can use orthographic projection for the sketch. Label the vertices $A-G$ and triangles $T1-T6$.

ii) Calculate the outer surface normals for triangle $T3$ and $T4$, i.e. the ones that are directed towards the viewer. Normalise the normal vectors.

iii) Is the polyhedral surface patch $T3-T4$ convex or concave? Show your reasoning through calculation.

iv) Is the polyhedral surface patch $T1-T6$ convex or concave? Show your reasoning. (Hint: no calculation required)

v) A viewing ray starting at the eye point intersects a view plane at $(1.5,0.5,-1.0)$. The view plane is parallel to the (x,y) plane and at location $z=-1$. Which triangle $T1-T6$ will be intersected by this ray? Show your reasoning.

b i) Briefly explain, using bullet points, which illumination effects can be achieved with ray tracing and how these effects are achieved. What is the key difference between ray tracing and radiosity?

ii) Outline the core ray-tracing loop in pseudo code as you would implement it in a GLSL fragment shader. Also show how to set up rays and how to terminate the algorithm.

iii) List three values computed during ray tracing and intersection calculation that are suitable ray termination criteria?

The two parts carry, respectively, 55% and 45% of the marks.

4 Rasterization, Anti-aliasing and hidden object removal

a Describe in detail two different approaches for anti-aliasing.

b Describe, using bullet points, the advantages and disadvantages of both anti-aliasing techniques.

c Describe the z-buffer algorithm in pseudo-code.

d What is a requirement for correct rendering of transparent objects? Assuming that this requirement is met, how can you render transparent objects? Be specific.

e Suppose we wish to rasterize a triangle given the screen space coordinates for their vertices as indicated in the diagram below

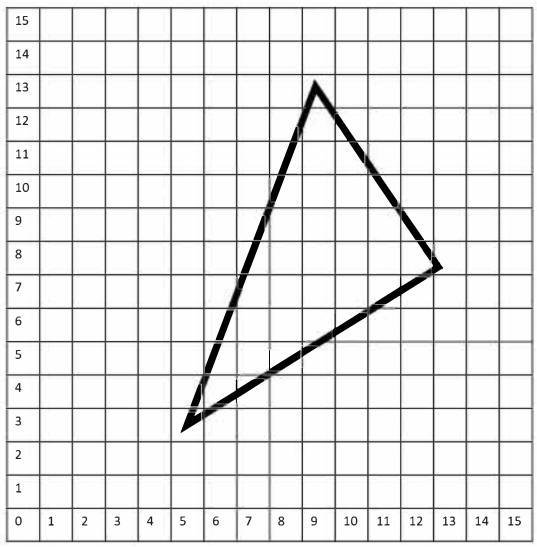

Fig. 3: rasterization of a triangle

i) If the line is rendered in black on a white background, a naive approach would be to fill in each pixel that contains any piece of the line. What is the common name for the aliasing effect that would result?

f Suppose the line has RGB colour (128, 200, 100) and the background has RGB colour (100,100,100). If the rasterization was antialiased using an obvious approach, what colour should pixel (5,3) be shaded? What colour should pixel (10,5) be shaded?

The six parts carry, respectively, 20%, 20%, 20%, 20%, 5%, and 15% of the marks.