Instructions to Candidates:

The exam accounts for 50% of the total marks for the subject.

Candidates should attempt all questions 1 to 6.

Marks for each question are shown. Total marks for the exam is 60.

Question 1

(a) Each of the diagrams below is of a right-handed, three-dimensional coordinate system with one axis missing. Draw each coordinate system in your exam booklet, showing all three axes — including the missing axis. Label the missing axis and state whether it points into or out of the page.

(b) A triangle $T_1$ has the vertices A(1,1,1), B(5,2,5) and C(3,4,2). Work out the plane equation of the plane in which $T_1$ lies.

(c) A different triangle $T_2$ has the three vertices D(1,2,2), E(4,1,-3) and F(4,4,1). Work out the plane equation of the plane in which $T_2$ lies.

(d) Which triangle from (b) and (c) has the largest $z$ value at (3,3)? Show your working.

(e) Assume a viewer is positioned at (3,3,1000) looking towards (3,3,0). Which triangle from (b) and (c) would they see at the pixel (6,2)?

(f) If the hidden surface problem was to be solved by back-to-front drawing of polygons, in which order would $T_1$ and $T_2$ have to be drawn to get a correct hidden surface solution for the viewing arrangement of (d)? Justify your answer.

\[(1+2+2+1+1+2 = 9 \text{ marks})\]
Question 2

(a) What are homogenous coordinates and why are they used in three-dimensional computer graphics?

(b) Give the transformation steps and the combined transformation matrix (CTM) which transforms the object shown below on the left into the object shown below on the right.

(c) Discuss the difference between a modelling transformation and a viewing transformation in OpenGL. Use a diagram, or diagrams, in your explanation.

(3+5+3 = 11 marks)

Question 3

(a) The *scan-line algorithm* for efficient rasterization of concave polygons uses an *edge table* and an *active edge table*. Give the algorithm, explain what these "tables" are and explain how they are used to realise an efficient algorithm.

(b) Draw diagrams showing the state of the edge table and the active edge table in the algorithm you gave as answer to (a) at scan lines $y = 0$, $y = 1$ and $y = 6$ for the polygon given below. Indicate the pixels which will be intensified on each of those scan lines.

(c) Polygons in OpenGL must be convex. Explain the efficiencies which can be achieved in the scan-line algorithm by handling only convex polygons.

(5+4+2 = 11 marks)
Question 4

A 3D games programmer is creating a robot which is to be animated using motion curves. He is starting with a simple wireframe box model which consists of a torso and two arms. The model contains the following joints: a left and right shoulder which can rotate around the z-axis. A rotation angle is stored for each joint. The depth of the torso and the limbs is 2, centred on the $xy$ plane.

(a) Assume the GLUT library provides a function `glutWireCube(GLfloat size)` which draws a cube of side length size centred at the origin. Using this function write a function `myWireBox(GLfloat width, GLfloat height, GLfloat depth)` which draws a wire box of dimensions width, height and depth at the current drawing position with the current drawing orientation in the current drawing colour.

(b) Write a function

```c
void display(void)
```

which draws the robot. Assume the viewing parameters, window initialisation, etc., have all been correctly set-up. Also assume there are two global variables `leftShoulder` and `rightShoulder` which control the rotation about the left and right shoulder.

(c) The animator has decided to animate the robot where it waves its arms around to indicate danger. The diagram below shows the robot at a number of points in time (keyframes).

Assuming linear interpolation between key frames, draw motion curves for the robot’s left and right arm.

(2+4+5 = 11 marks)
**Question 5**

OpenGL supports a range of rendering modes. In the diagram below a cylinder has been rendered in five different ways.

![Cylinder renderings](image)

(a) Describe the most important features of each rendering, explain what the settings or modes of the OpenGL state machine need to be to produce it and give the OpenGL command which applies to each setting or mode required.

(b) Discuss the possible effect of each type of rendering on the frame rate in a real-time animation.

(6+3 = 9 marks)

**Question 6**

(a) Explain what you understand of the following lighting equation.

\[ I_\lambda = I_a + k_a O_d \lambda + f_{att} I_p \lambda [k_d O_d \lambda N \cdot L + k_s (R \cdot V)^n] \]

Use diagrams to clarify your answer. What changes, if any, are required to handle multiple light sources?

(b) Explain what is meant by, and discuss and relationship between, the terms: Gouraud shading, Phong shading, flat shading and smooth shading.

(6+3 = 9 marks)

**THE END**