The University Of Sheffield.

Data Provided: None

DEPARTMENT OF COMPUTER SCIENCE **Autumn Semester 2016-2017**

3D COMPUTER GRAPHICS **2 Hours**

Answer THREE questions only.

All questions carry equal weight. Figures in square brackets indicate the percentage of available marks allocated to each part of a question.

1. a) Figure 1 shows a quadcopter model made entirely from spheres, where each sphere is transformed into the required shape for the particular part. The central body of the quadcopter has four arms attached to it. Within each arm, at the end of the horizontal piece, the darker-coloured sphere contains an engine to rotate the rotor blade assembly attached above it. A rotor blade assembly consists of a sphere and two rotor blades, each of which is tilted slightly in its direction of travel.

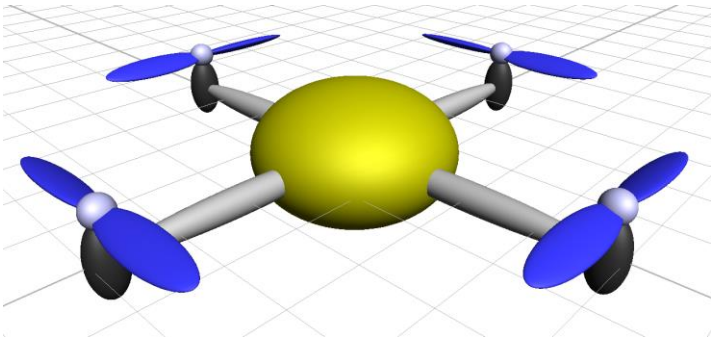

Figure 1. A quadcopter toy. The grid of lines is the xz plane.

(i) Draw a scene graph for the model – you do not need to add transformations to the scene graph. Indicate repetition where appropriate in your scene graph so as to shorten the length of your answer.

[10%]

(ii) State where you would place transformations in your scene graph for a vertical ascent (take-off). As the quadcopter ascends, the rotor blades should rotate around their respective vertical axes.

[10%]

(iii) Write pseudocode to draw a single arm. In your answer, assume that the method `sphere(r)` exists, which draws a sphere of radius r centred on the world origin, and that the standard transformations can be written as `scale(x,y,z)`, `translate(x,y,z)` and `rotate(angle, x,y,z)`, where angle is the anticlockwise angle around the axis (x,y,z). The exact size of the pieces is not important, nor are the exact parameters for a transformation. Instead, you should give approximate parameters for the size of the pieces and approximate parameters to indicate which axis or axes the transformation applies to, e.g. `translate(0,0.5,0)` indicates that the translation should occur in the positive direction along the y axis; whether it should be 0.5 or 0.9 or some other number is not important. The specific transformations that are used and their combination and order is the most important part of the answer. The OpenGL commands `glPushMatrix()` and `glPopMatrix()` should be used where appropriate, and can be written as `push` and `pop`, respectively, to shorten your answer.

In order to structure your answer, you should first write the following functions in pseudocode: `drawHorizontalBar()`, `drawEngineSphere()`, `drawRotorCentreSphere()`, and `drawRotorBlade()`, which draw the parts of the quadcopter that their names suggest. You should give each of these functions the parameters you think they will need. Once these functions are written, you should then write the pseudocode to draw a single arm.

[40%]

b) The body of the toy quadcopter is to be replaced by a more complex polygon mesh model.

(i) Consider one of the triangles from this mesh and a camera at the world coordinate position $(0, 0, 5)$ pointing in the direction of the world origin. The triangle has coordinates $\mathbf{p_0} = (0, 0, 0)$, $\mathbf{p_1} = (1, 0, 0)$, and $\mathbf{p_2} = (0, 1, 0)$, with the triangle normal pointing in the direction $(\mathbf{p_1} - \mathbf{p_0}) \times (\mathbf{p_2} - \mathbf{p_0})$, where $\times$ represents a cross product. Should this triangle be back face culled? For full marks, you must explain your reasoning using relevant vectors.

Note: The cross product for vectors $\mathbf{a} = (a_x, a_y, a_z)$ and $\mathbf{b} = (b_x, b_y, b_z)$ is given by $\mathbf{a} \times \mathbf{b} = (a_y b_z - a_z b_y, a_z b_x - a_x b_z, a_x b_y - a_y b_x)$.

[10%]

(ii) Given polygon normals for the mesh, describe how you would calculate the associated vertex normals.

[10%]

d) The quadcopter is rendered using the z-buffer algorithm. Describe how two memory buffers are used in the z-buffer approach to hidden surface removal. Pseudocode can be used in your answer.

[20%]

2. a) The following equation represents the Blinn-Phong local reflection model:

$$I = I_a k_a + I_L k_d (L.N) + I_L k_s (N.H)^n$$

(i) Explain what real effects the second and third terms are trying to model.

[10%]

(ii) Describe the vectors $\mathbf{L}$, $\mathbf{N}$ and $\mathbf{H}$ and draw a diagram that illustrates them for a point on a surface. As part of the description, state any assumptions that are required so as to interpret the vectors, and label any extra vectors on the diagram to help with this description.

[15%]

b) Briefly describe Phong interpolative shading.

[15%]

c) Assume the Blinn-Phong equation is being used to calculate lighting values. A point light source is located along the vector direction (5,5,0). A cube with sides of length 1 is centred on the world origin.

(i) If the cube is completely diffuse, state the position, or positions, a viewer could be in and what direction, or directions, they would be looking in to see maximum reflected light. Explain your reasoning by referring to the Phong equation.

[10%]

(ii) If the cube is completely specular, state the position, or positions, a viewer could be in and what direction, or directions, they would be looking in to see maximum reflected light. Explain your reasoning by referring to the Phong equation.

[10%]

d) Two common approaches used to produce shadows in polygon mesh rendering are shadow maps (i.e. the shadow z-buffer approach) and shadow volumes. Briefly contrast the two approaches with respect to each of the following statements, making sure you comment on each approach in your answers:

(i) The approach allows objects to cast shadows on themselves (i.e. self-shadowing);

[10%]

(ii) The approach renders the scene geometry from the viewpoint of the light;

[10%]

(iii) The approach generates extra geometric primitives;

[10%]

(iv) The resolution of the intermediate representation used in the approach can result in problems with aliasing.

[10%]

3. a) An animated film is to be made in which a timid, plastic alligator (a child's toy with a surface covered in bumps) makes friends with a model of a crocodile made of old wood that has knots in its grain. They wander around a wooden tabletop, observe reflected images of themselves in a polished, highly-reflective, metal paperweight, which is approximately spherical in shape, see a map of the world on the cover of a book, and decide to find out if they come from the same part of the world. A model of this tabletop scene is required. Describe (with diagrams) and justify texturing techniques that could be used to improve rendering realism for each of the following objects in the scene, where each object is modelled using a polygon mesh, and a different texturing effect is used for each object:

   (i) The alligator;

   [20%]

   (ii) The paperweight;

   [20%]

   (iii) The book;

   [20%]

   (iv) The crocodile.

   [20%]

   b) As part of the animated film, extremely close-up views will be required for each of the objects in 3(a). In addition, the alligator and crocodile will each need to walk. Briefly discuss the issues that both these considerations will raise and state whether or not you would change the texturing techniques chosen in answer to 3(a) and, if so, which techniques you would choose.

   [20%]

4. a) Using a list of bullet points, describe how a standard naïve ray tracer works. As part of your answer, explain why the images it produces have a particular signature.
[40%]

b) Within a ray tracer, three different bounding volumes that could be used to surround objects are bounding spheres, AABBs and OBBs, each of which could also be used in a hierarchy of bounding volumes. Compare and contrast their relative efficiency (including hierarchies) for bounding a group of flying teapots, which are behaving like a flock of birds, where each teapot is continually re-orientating itself within the flock as it moves, and the flock may break apart and then the sub-flocks may subsequently join together. As part of your answer, clearly state which bounding volume approach you would choose, and why, as part of a ray tracer. Use the following three criteria to help structure your answer:

- The trade-off between tightness of fit and intersection speed;
- The update of the bounding volume as the object moves;
- The effect of hierarchies of bounding volumes on the above two criteria.

[30%]

c) Consider a ray tracer applied to a three-dimensional scene containing n teapots, where each teapot is a polygon model composed of m polygons. The scene is illuminated with 3 point light sources and the program is rendering onto a screen of dimensions width w and height h. The program is to render 'geometric' or hard-edged shadows.

(i) In terms of n, m, w and h, how many polygon intersection tests are invoked for the first generation (i.e. initial) rays for the set of screen pixels (not including shadow calculations)?
[5%]

(ii) Assuming 20% of the initial rays hit a teapot, what is the minimum and maximum number of polygon intersection tests that are invoked for shadow calculations for the first generation of rays?
[10%]

(iii) Assuming 20% of the initial rays hit a teapot, how many polygon intersection tests are invoked for the second generation of rays (not including shadow calculations)? Would this result change if all the objects were spheres instead of teapots? Explain your answer.
[10%]

(iv) Following on from 4(c)(iii), assuming 30% of the second generation rays hit a teapot, what is the maximum number of polygon intersection tests that are invoked for shadow calculations for the second generation of rays?
[5%]

END OF QUESTION PAPER