The University of Calgary

Department of Computer Science

Final Examination, Questions

ENEL/CPSC 555 Computer Graphics

Time: 2 Hours

Closed Book, calculators are permitted. The questions carry equal weight. Full marks (out of 30) will be given for correct answers to five questions.

1. (Ray Object Intersection Calculations)

   (a) A ray intersects the plane of a triangle at the point $(1,\ 0, 2)$. Is the point inside the triangle given by the following vertices: $(-4,\ 0, 4)$, $(4,\ 0, 0)$, $(0,\ 0, -4)$
   Describe a good test to determine if a point is inside the triangle in the context of a ray tracer.

   (b) How is a ray sphere intersection calculated?

   (c) How can an ellipsoid be ray traced without having to calculate a ray ellipsoid intersection test? Describe the algorithm and transformations involved.

2. (Shading)

   (a) The Phong light model is used to shade a polyhedron consisting of 100 polygons that approximate a sphere. Two images of the sphere are made using Gouraud and Phong shading respectively. If a single light source is positioned at the same point as the viewer, describe the appearance of the two images in terms of the diffuse and specular shading that would be observed.

   (b) In a ray tracer the viewer is placed at $(0,\ 0,\ 0)$ looking down the positive z-axis towards a unit sphere placed at $(0,\ 0,\ 5)$. An animation is made with a light source starting at the same place as the viewer and orbiting around the sphere in the $(x,\ z)$ plane. The sphere has a high specular component. Sketch a few sample frames showing the resulting diffuse and specular lighting on the sphere as it changes with the position of the light source.

3. (Rendering)

   (a) Describe how a triage table can be used to implement Warnocks algorithm.

   (b) Show how in the A-buffer algorithm, the partial coverage of a pixel by a polygon fragment can be calculated.

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4. (Clipping and Scan Conversion)

   (a) In the Cohen and Sutherland clipping algorithm, it is required to clip a number of lines against a screen area starting at $(100,\ 100)$ and opposite corner at $(200,\ 200)$. Calculate the end point codes for the following lines: $(240,\ 0)\ to\ (150, 150)$

   $(50,\ 150)\ to\ (150, 50)$

   $(150,\ 120)\ to\ (180, 120)$

   $(150,\ 250)\ to\ (150, 50)$

   Which lines will be further clipped?

   (b) Describe what is meant by the term *re-entrant* for the Sutherland-Hodgeman polygon clipping algorithm. What are the four cases that are considered when comparing a polygon edge to each edge of a clip rectangle?

5. (Ray Tracing)

   (a) In a ray tracer a user sets the viewer eye position, $VP\ (4,\ 10,\ 18)$ looking at the point $LP\ (0,\ 1,\ 2)$. How is this point of view and lookat point implemented in a ray tracer? Show the matrix and vector calculations necessary to use these values of VP and LP.

   (b) In a ray traced image of a single sphere under a single light source coincident with the viewer, a number of black pixels are observed. What is a likely cause of this bug?

   (c) The above bug has been fixed, but when several reflective spheres are modelled, black patches are observed on the surface of the spheres. What is a likely cause of this new bug?

6. (Miscellaneous)

   (a) Why does a point of inflection in a curve cause a problem if a generalised cylinder is being built around the curve?

   (b) Write brief notes on space subdivision for improving the efficiency of ray tracing.

   (c) An edge of a triangle cuts a particular pixel into two portions so that the lower third is covered by the triangle. Describe a way in which such a pixel can be sampled in a ray tracer to achieve an anti-aliased image.

7. (Shading)

   (a) A raft floats in the Indian ocean 600m off the coast of Africa at the Equator. On the raft is a shiny gold coin. A pirate stands on top of a 300m high cliff. Assuming it is mid-june, at what time of day will the Pirate see the gold coin. State any assumptions that you make and show all your working. (Hint) The pirate will only see the coin by its specular reflection.

   (b) In a simulation of the above example the Phong illumination model is used. Describe the visible difference between rendering the scene using Gouraud shading and Phong Shading.

   (c) A unit square lies in the $y = 0$ plane, the centre of the square is at the origin. A light source, is placed at a large distance along the positive x-axis, and rotated about the z-axis counter clockwise. Sketch a graph showing how the illumination at the centre of the square changes as the light source is rotated around the centre of the square by 2π radians.

1 Question 2 (20%) Ray Tracing

(a) A three units long cylinder, radius 0.5 is modelled with its long axis aligned with the y-axis, and the x and z-axes intersect the cylinder half way up its long axis. It is transformed into the world space by rotating it by $pi/4$ radians around the z-axis, and translating it to the point $(1, 1, 5)$. A ray is fired from the origin in the direction $(0.138675, 0.138675, 0.980581)$.

In pseudo-code, describe an algorithm for finding the ray cylinder intersection. Write down any transformation matrices that you use. How general is your algorithm?

2 Question 3 (20%) Implicit Modelling

(a) Two sphere primitives, A and B are defined by skeletal points whose field contributions falls to zero at distances 2 and 3 respectively. The two spheres are placed with their centres at a distance 3 units apart. Make a 2D sketch showing the plane through the centre of the two spheres. Sketch the 0.5 contour and the 0.0 contour using the field function: $F(r) = (1 - r^2)^2$

(b) Explain the ambiguity in the polygonization of cubic voxels defined in the uniform space subdivison algorithm (given in the notes), when diagonal vertices have the same sign and are oppositely signed to the other diaganols on the same face? What larger problem is indicated by this discrepency? How can the above problem be solved using tetrahedra? What are the advantages and disadvantages of using tetrahedra?

8. (Rendering and Ray Tracing)

   (a) How would you extend Warnocks algorithm to produce anti-aliased images?

   (b) Make brief notes comparing uniform space subdivision and bounding spheres as methods for speeding up ray tracing.

   (c) In a ray tracer using uniform space subdivision, a bug occurs so that objects are often clipped along vertical planes. What is a likely cause of the bug?

   (d) What is meant by a *ray signature*?

   (e) In a ray tracer, some objects have dark speckles in areas which should be bright. What is a likely cause of the bug?

9. (Shading)

   (a) The specular exponent is most relevant to which of the following:

      i. a.Gouraud shading
      ii. b.Phong illumination
      iii. c.Generalized cylinders
      iv. d.Phong shading

   (b) In a scene with a single directional light source with direction $(0, 1, 0)$ and the following triangle:

      Vertices: $(-1, 0, 0), (0, 0, 1), (1, 0, 0)$
      Normals: $(-1, 1, -1), (0, 1, 1), (1, 1, -1)$

   (c) Two images of the triangle are rendered from the same point of view. The images show all three vertices of the triangle and both use the Phong illumination model. The first image is rendered with Gouraud shading and the second with Phong shading. Describe the visual difference between the images with respect to the position and appearance of the specular reflection.

      Draw a diagram indicating a point in space from which a viewer will see maximum brightness of the specular highlight.

10. (Ray Tracing)

   (a) Given the cylindrical surface: $f(x, y, z) = x^2 + z^2 - 1 = 0$, and a ray with position (0,0,0) and direction (0,0,1), intersect the surface with the ray, where the surface is transformed by the following :

      rotate about z 90 degrees.
      translate in x by 2 and z by 5

      [Order of the transformations is as given above. Rotation is counter-clockwise for positive angles when looking down the positive z-axis towards the origin.]

      What is the object/modeling space intersection point? In which space (modelling or world) is the intersection test performed for transformed primitives and why?

   (b) A naive ray tracer is used to render a scene consisting of 10 spheres. Calculate the number of intersection tests using the following data:

      640x480 pixels, 10 spheres 5 reflective and 5 non-reflective, maximum recursion depth is 1 (i.e. primary rays are reflected once) and two light sources, every ray produces an intersection, shadow rays are tested against every object. A ray has equal chances of hitting a non-reflective or reflective sphere.

      Choose one of the following answers. If you choose *none of the above* show your calculation of the number of intersection tests.

      i. 1,536,020 totally bogus
      ii. 3,072,000 640x480x10
      iii. 3,072,020 640x480x10+20
      iv. 4,608,020 640x480x10+640x480x10/2+20
      v. 4,608,040 640x480x10+640x480x10/2+20+20
      vi. none of the above.

(c) In an implicit surface modelling system the field function is defined as

$$f(r) = \begin{cases} 1 & r < 0 \\ 0 & r > R \\ 1 - r/R & o/w \end{cases} \quad (1)$$

where R is a constant. Two line segment skeletons a, and b, co-linear with the x-axis are placed so that their end points are touching.

Which sketch (shown below) of the cross section of the $F(r) = 0.5$ surface is possible? The field function is given as: $F(r) = f_a(r) + f_b(r)$ and r is the closest distance of a point from the skeleton.

(a)

(b)

(c)

(d)

Where is the distance from the surface to the line skeletons a maximum?

What is that distance, in terms of R?

(d) i. Consider the following two parametric curve segments:
$f(t) = (t^2 - 1, t)$
$g(t) = (t^2 + 1, t + 1)$
Show that the segments are G^1 and G^2 continuous at : $f(1) = g(0)$, $f'(1) = g'(0)$ and $f''(1) = g''(0)$.

ii. Write brief notes describing how the continuity of B-spline curve segments may be reduced and lead to conditions for a B-spline to become a Bezier spline.