CS_307 Computer Graphics II: Modelling and Rendering

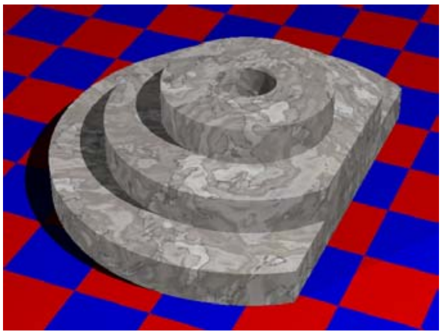
January 2005

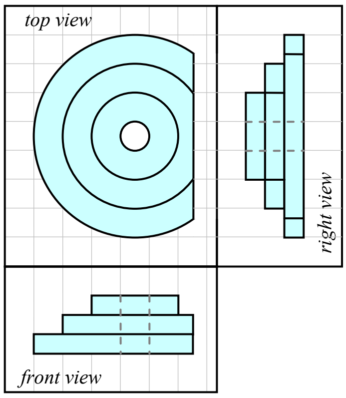
(Attempt 2 questions out of 3)

Question 1.

(a) Given a 3D solid object as illustrated on the right, suggest a method for representing it in the computer, and with the aid of a diagram and appropriate operators, describe how you would model the object using the method.

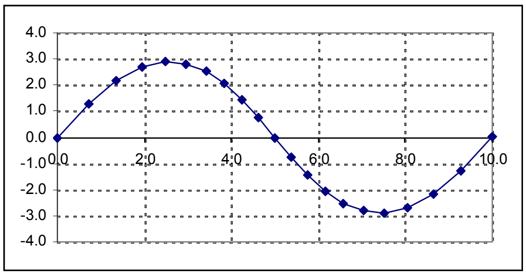
[6 marks]



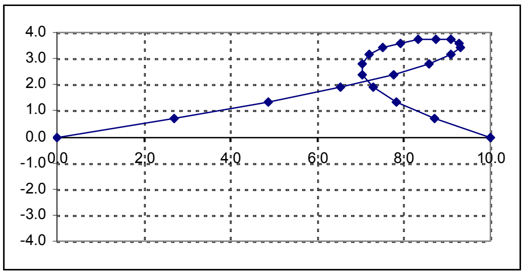


(b) Consider the following seven sets of control points for 2D Bézier curves.

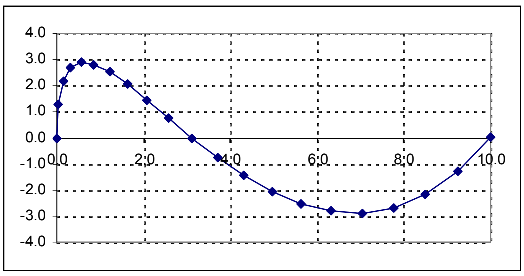
	$P_1(x, y)$	$P_2(x, y)$	$P_3(x, y)$	$P_4(x, y)$
A:	0, 0	5, 10	5, 10	10, 0
B:	0, 0	5,10	5, -10	10, 0
C:	0, 0	5, -10	5, 10	10, 0
D:	0, 0	0,10	5,-10	10, 0
E:	0, 0	0,10	10,-10	10, 0
F:	0, 0	10,5	0,5	10, 0
G:	0, 0	20,5	0,5	10, 0



(a)



(b)



(c)

(i) For each curve shown on the right, identify the corresponding set of control points? (Hint, you may eliminate most cases simply by observation.)

(ii) From curves A-E, identify one set of three *different* curves which may join together such that the first order geometric continuity (G^1) is maintained. State the order in which these curves are joined together.

(iii) What is the equivalent Hermite representation for curve A? Briefly explain your answer.

(iv) If a polyline of 3 points is used to draw curve F, calculate the coordinates of the three points. The Bézier matrix $\mathbf{M_B}$ is shown on the right.

$$\begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

[10 marks]

(c) Describe an application of volume visualisation and the nature of its volumetric data. In the context of volume data, explain the terms *scalar field* and *iso-surface*.

In the context of volume visualisation, consider the marching-cubes algorithm and its 2D version, *marching squares*. Outline the main algorithmic steps of the marching squares algorithm for constructing a contour from a grey scale image with a pre-defined threshold value. Given a threshold (iso-value) and a square cornered by four pixels, list all six possible patterns of pixel values in relation to the threshold, and the corresponding intersection(s) between the contour and the square.

What kinds of patterns may lead to some ambiguities in determining intersection(s)? As examples, give one 2D pattern in *marching squares*, and one 3D pattern in *marching cubes*.

[9 marks]

Question 2.

(a) A 3D object is first scaled with scaling factors $(\mathbf{S_x}, \mathbf{S_y}, \mathbf{S_z}) = (\mathbf{2}, \mathbf{2}, \mathbf{1})$ relative to the origin, and is then rotated about the z-axis by 90 degrees relative to a fixed point $(\mathbf{T_x}, \mathbf{T_y}, \mathbf{T_z}) = (\mathbf{2}, \mathbf{1}, \mathbf{0})$. Calculate the composite transformation matrix which performs these two operations.

[5 marks]

(b) An illumination model for computing the intensity of light reflected from a surface is given below:

$$\mathbf{I} = \mathbf{I_a k_a} + \frac{1}{\mathbf{a_0} + \mathbf{a_1 d} + \mathbf{a_2 d^2}} \mathbf{I_p}\left[\mathbf{k_d}\left(\vec{\mathbf{L}} \bullet \vec{\mathbf{N}}\right) + \mathbf{k_s}\left(\vec{\mathbf{V}} \bullet \vec{\mathbf{R}}\right)^{\mathbf{n}}\right].$$

(i) With the aid of a diagram, explain what directions are represented by vectors $\vec{\mathbf{L}}$, $\vec{\mathbf{N}}$, $\vec{\mathbf{V}}$ and $\vec{\mathbf{R}}$ respectively.

(ii) Describe the functions of $\mathbf{k}_a$, $\mathbf{k}_d$ and $\mathbf{k}_s$ in the model.

(iii) Describe the effect of varying parameter $\mathbf{n}$.

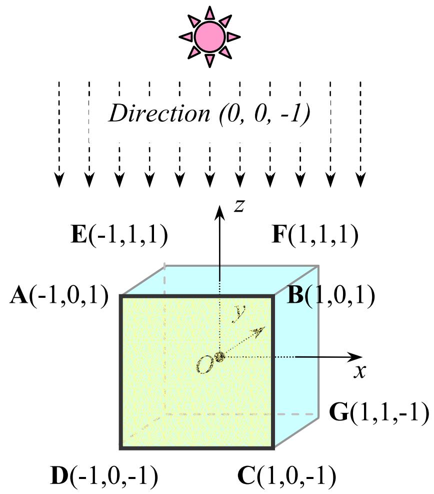
(iv) $\frac{1}{\mathbf{a_0} + \mathbf{a_1 d} + \mathbf{a_2 d^2}}$ is usually replaced by $\mathbf{min}\left(1, \frac{1}{\mathbf{a_0} + \mathbf{a_1 d} + \mathbf{a_2 d^2}}\right)$ in practice. Explain why.

[8 marks]

(c) Consider the front face **ABCD** of a cube that is lit by a distance light source as shown on the right. We assume that all points on edges **AB**, **BC**, **CD** and **DA** belong to face **ABCD** only. We also assume that the light intensity of the cube is calculated based on the illumination model given in (b) with

$$\mathbf{I}_p=1,\ \mathbf{k}_a=0,\ \mathbf{k}_d=1,\ \mathbf{k}_s=0,\ \mathbf{a}_0=1,\ \mathbf{a}_1=0,\ \mathbf{a}_2=0.$$

For each of the following shading methods determine the brightest and darkest parts of face **ABCD**. [Hint: it is not necessary to give exact intensity value, and it is possible that there is more than one brightest (or darkest) point.]



(i) Constant shading, (ii) Gouraud shading, (iii) Phong shading.

[5 marks]

(d) Consider the first assumption of question (c) that all points on edges **AB**, **BC**, **CD** and **DA** belong to face **ABCD** only. Discuss why removing this assumption may affect the results of the constant shading, but not the results of the other two shading methods. [Hint: consider what would be the colour of each pixel on a projected edge, if the edge is projected onto the image plane more than once as part of different faces.]

Briefly describe the *z-buffer algorithm* for hidden-surface removal. Consider the application of constant shading, in conjunction with the *z-buffer algorithm*. Explain how edge **AB** may be displayed differently with different orders of faces in the data structure, if we do not assume that all points on edge **AB** belong to face **ABCD** only.

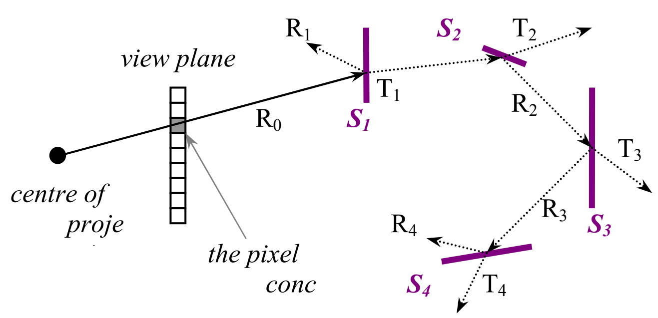
[7 marks]

Question 3.

(a) What is meant by the term *vanishing point* in the context of projection? Which type of projection usually features vanishing points? With the aid of a diagram, show an appropriate projection of a cube, which features three vanishing points. With the aid of another diagram, design an object and show an appropriate projection of the object, which features more than three vanishing points.

[6 marks]

(b) The figure on the right illustrates a ray tracing tree. There are four surfaces, S_i (i=1, 2, 3, 4), in the scene. The primary ray R_0, which is NOT perpendicular to the view plane, passes through a pixel on the view plane. All the possible secondary rays, R_i and T_i (i=1, 2, 3, 4), are indicated by dotted lines.



We assume that the scene is lit by only white ambient light, the background is black, and all surfaces are of the same colour. The light intensity of each surface and its physical properties are given in the table on the right.

Object	Light intensity	Reflection Proportion	Refraction Proportion
S_1	0.5	0.1	0.2
S_2	0.5	0.6	0.2
S_3	0.5	0.0	0.8
S_4	0.5	0.6	0.3

What is the light intensity to be drawn at the *concerned pixel* after ray tracing? Show all the main calculation steps.

Which of the following changes to the conditions would result in a different light intensity of the pixel? Briefly explain your answer for each change.

(i) Changing the light intensity of surface S_4;
(ii) Changing the refraction indices of surface S_1;
(iii) Moving the centre of projection away from the view plane in the opposite direction of the view plane normal;
(iv) Introducing depth cueing;
(v) Introducing tree-depth control by discarding any ray at recursion level 4 or more;
(vi) Introducing adaptive tree-depth control by discarding any ray whose (estimated) proportion of contribution is less than 0.15.

[10 marks]

(c) With the aid of diagrams, design a railway-driving simulator to be implemented in an appropriate graphics API such as VRML. (You are not constrained by a particular API.) Describe how you would deal with various modelling issues using appropriate modelling and rendering techniques, and how you would facilitate the dynamic changes on the driver's screen. For each technique that you wish to employ in this application, you should give a brief description and discuss its merits in relation to the requirements of the application. Your discussions *may* include, but are not limited to, the following techniques and modelling issues:

Techniques: geometrical transformation, viewing transformation, 3D clipping, hidden-surface removal, illumination, texture mapping, polygonal meshes, parametric cubic curves and bi-cubic surfaces, constructive solid geometry, fractals, sweep representation, and other graphics techniques which you are knowledgeable.

Modelling Issues: railway tracks, bridges, tunnels, plants, mountains, clouds, water, stations, people, motion, vibration, and other issues appropriate to this application.

[9 marks]