CS_307 Computer Graphics II: Modelling and Rendering
January 2004
(*Attempt **2** questions out of 3*)

Question 1.

(a) With the aid of diagram, show the main functional modules of a graphics pipeline. For each of the following methods, indicate its relevance to the graphical pipeline by associating it to a particular part(s) of the pipeline.

(i) radiosity computation,	(ii) viewing transformation,
(iii) texture mapping	(iv) winged-edge representation,
(v) parametric surfaces,	(vi) motion specification

[5 marks]

(b) A triangular mesh, which approximates a sphere, was rendered using three different basic shading methods respectively. All three methods are based on projecting and scan-converting each triangle in the mesh, and the results are shown below:

(A) (B) (C)

(i) Name these three shading methods, and associate each method with the appropriate resultant image.
(ii) Outline the main algorithmic steps of the shading method used for image (B), and describe how vertex normals are calculated.
(iii) Discuss why the method used for image (B) has failed to display specular highlight, as shown in (C), in this particular example.

[10 marks]

(c) A 2D Bèzier curve is defined by the following control points:

$$P_1(0, 1), P_2(5, 5), P_3(5, -5) \text{ and } P_4(0, -1)$$

(i) If a polyline of total **6** vertices is used to display this curve, calculate the coordinates of the first two vertices of the polyline. The Bèzier matrix M_B is shown on the right.

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

(ii) Give the control points of another Bèzier curve that joins the above curve at $P_4(0, -1)$ such that the first order geometric continuity (G^1) is maintained.

[5 marks]

(d) *see page 2*

(d) The parametric representation of a Bézier surface patch is given as follows:

$$P(s,t) = S \cdot M_B \cdot G_x \cdot M_B^T \cdot T^T =$$

$$\begin{bmatrix} s^3 & s^2 & s & 1 \end{bmatrix} \cdot \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ P_{21} & P_{22} & P_{23} & P_{24} \\ P_{31} & P_{32} & P_{33} & P_{34} \\ P_{41} & P_{42} & P_{43} & P_{44} \end{bmatrix}_x \cdot \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix}$$

where $P(s,t) = [x(s,t), y(s,t), z(s,t)]$ gives the position of every point on the patch.

(i) With the aid of a diagram if necessary, describe what are s, t and G_x.
(ii) How would you approximate this patch using a mesh consisting of 4×5 quadrilateral elements (i.e., 5×6 verices)?
(iii) Is each quadrilateral assured to be flat? Briefly explain your answer.

[5 marks]

Question 2.

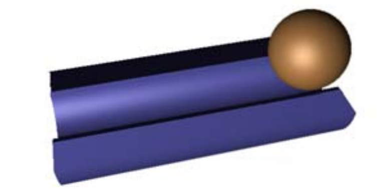
(a) A 3D object is first scaled with scaling factors (s_x, s_y, s_z) = (**2**, **1**, **2**) relative to the origin, and is then rotated by **90** degrees about an axis that is parallel to the z-axis and passes through the point (**2**, **2**, **0**). Calculate the composite transformation matrix which performs these two operations.

[5 marks]

(b) Describe the concepts of Constructive Solid Geometry (CSG), including *regularisation*. With the aid of appropriate CSG trees (or CSG terms), describe how you would specify the two composite objects using the three available primitive objects (as shown below). It is necessary to give precisely the regularised Boolean set operators used, but not the geometrical transformations involved.

primitives **A**, **B**, **C**

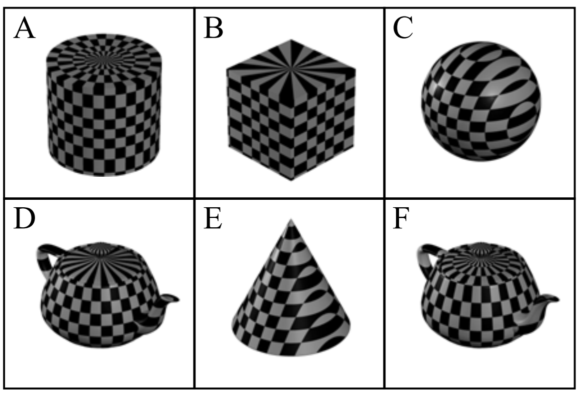
composite object **X**



composite object **Y**

[6 marks]

(c) A regular chess board pattern is texture-mapped onto the objects on the right using "planar", "cylindrical" and "spherical" mapping methods. For each object, identify the mapping method used.

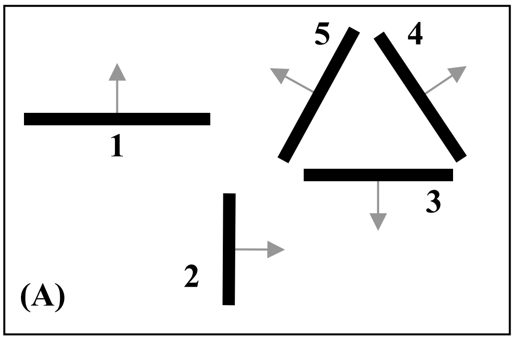


Describe the basic concept of "bump mapping" and its use.

[5 marks]

(d) *see page 3*

(d) In the context of hidden surface removal, consider a 2D scene, which consists of 5 line segments as shown on the right. Construct a binary space partition (BSP) tree using *Fuchs et al*'s BSP method. Assuming that the root and internal nodes (sub-roots) are selected according to the ascending numerical order of indices. In other words, within a group of line segments, it is always the segment with the smallest index chosen to become the partitioning line. In the constructed tree, the left/right (front/back) arrangement of the tree must follow the normal direction (indicated by an arrow) of each partition line.



Is BSP tree an object-space, image-space or combined method for hidden-surface removal?

If (A) is the viewing position, and all line segments are projected towards (A), in what order would these lines in your BSP tree be projected?

Construct another BSP tree that minimises the number of splits by selecting an appropriate line segment as the partitioning line as each stage.

[9 marks]

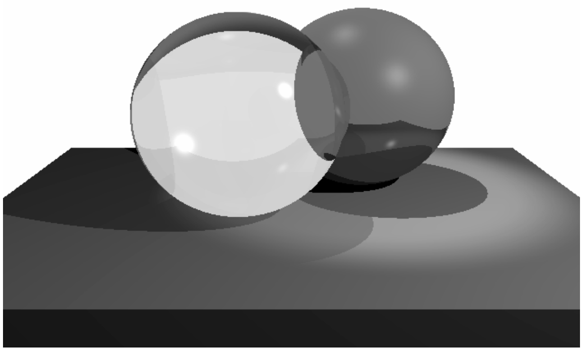
Question 3.

(a) With the aid of diagrams, contrast the eye ray tracing (backward) and the photon ray tracing (forward) methods (in about 150-250 words).

With the aid of diagrams, contrast the intersection-based ray tracing used in surface graphics and the discrete ray tracing used in volume graphics and volume visualisation (in about 150-250 words). You need only consider the eye ray tracing mechanism for both approaches.

[8 marks]

(b) The image shown on the right is synthesised using eye ray tracing. Using this image as an example, and a sketch of the possible scene, describe the concepts of reflection and refraction in eye ray tracing.



With the aid of the same example, describe how shadows are determined in an eye ray tracing algorithm.

In most cases, pixels in a shadow are also illuminated. What kind of light sources may such pixels receive the light from? Indicate those light sources that are normally considered only by the photon ray tracing method.

[7 marks]

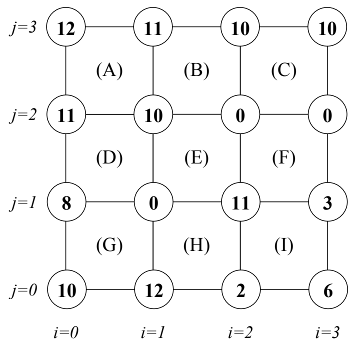
(c) *see page 4*.

(c) 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), T, 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*.

Consider the 4×4 grey scale image on the right, where pixel values, $v_{i,j} \in [0, 12]$, are shown inside circles. Given a threshold $T = 5$, compute a contour line in square (D), and give the two endpoints of the line in relation to the grid coordinates. (Hint: the contour line in (C) is [2, 2.5] — [3, 2.5].)



With $T = 5$, which squares in this image exhibit ambiguous patterns, which can be resolved using asymptotic decider?

Describe an application of volume visualisation and the nature of its volumetric data.

[10 marks]