# PAPER C317

# GRAPHICS

Wednesday 18 March 2020, 15:00
Duration: 120 minutes
Post-processing time: 30 minutes
*Answer THREE questions*

Paper contains 4 questions

1 Textures

Raster images are used to enhance the details of surface meshes. The process of virtual wrapping of images around polyhedral geometry is called *texture mapping*.

a i) Sketch a graphics pipeline that includes texture mapping.

ii) Identify the part in the graphics pipeline during which texture mapping is performed.

iii) Which coordinate transformations are required to convert from the identified part in the graphics pipeline to two-dimensional texture space? Name the used coordinate axes $(x, y, z)$, $(u, v, w)$, and $(s, t, p)$ according to the commonly used naming convention for texture mapping.

b When texture coordinates are added as additional parameters to vertices, these parameters are interpolated during the rasterization stage like any other payload parameter (colour, normal, etc.).

i) Will such an interpolation result in correct texture coordinates for all fragments? Justify your answer.

ii) Name two different and valid schemes to convert screen space fragment coordinates to texture coordinates.

c Textures are usually sampled from a normalised coordinate space mapped to $(0 <= s <= 1, 0 <= t <= 1)$. Name four common schemes to handle out-of-bounds samples when texture coordinates are sampled $(s < 0||s > 1, t < 0||t > 1)$.

d Given are two points $p'$ and $r'$ that have been projected onto a viewing plane from $p = (x_p, y_p, z_p)$, $r = (x_r, y_r, z_r)$ and a point $q'$ on the projected line between $p'$ and $r'$. How would you calculate the (s,t) texture coordinates of $q'$ using perspective correct interpolation if $f = 1$ in the projection matrix. You can either derive the process mathematically or describe it in bullet points.

e Describe in detail two different approaches for anti-aliasing. Describe, using bullet points, the advantages and disadvantages of both anti-aliasing techniques.

f Describe *bump mapping* using three bullet points.

i) what is needed and what is manipulated?

ii) what is the aim of this technique?

*The six parts carry, respectively, 20%, 10%, 20%, 20%, 20%, and 10% of the marks.*

2 Ray tracing

a Briefly explain which illumination effects can be achieved with ray tracing and how these effects are achieved. What is the key difference between ray tracing and radiosity?

b A simple ray tracing algorithm consists of ray generation, ray processing, intersection evaluation parts and termination criteria.

i) Outline the core ray-tracing loop in pseudo code as you would implement it in a GLSL fragment shader. Also show how to set up rays and how to **terminate** the algorithm.

ii) Which values computed during ray tracing and intersection calculation would be suitable ray termination criteria?

c How can the GLSL programmable graphics pipeline be conceptionally forced to process one fragment per output pixel and to provide a ray direction for every fragment?

i) How is this approach usually called?

ii) Describe this approach schematically. Avoid using actual OpenGL/GLSL syntax.

iii) Naïve shadow generation will lead to so called 'self-shadowing' artefacts. Describe the reason for these artefacts and possible corrective measures.

iv) Simple shadow computation approaches produce hard shadows. Describe a potential way to generate *soft shadows* to simulate more natural lighting conditions. Name one disadvantage of calculating *soft shadows*.

d A ray originates at point $V = (0, -1, 18)$ and has a direction vector $d = (0, 2, -8)$. The points of a triangle are given as $P_1 = (-6, -2, 0)$, $P_2 = (6, -2, 0)$, and $P_3 = (0, 6, 12)$.

- Calculate whether the ray intersects the face defined by the triangle and if yes, state the point coordinate of the intersection and intermediate results for terminal values of your intersection calculation algorithm.
- draw a sketch of the triangle and ray.

*The four parts carry, respectively, 15%, 25%, 30%, and 30% of the marks.*

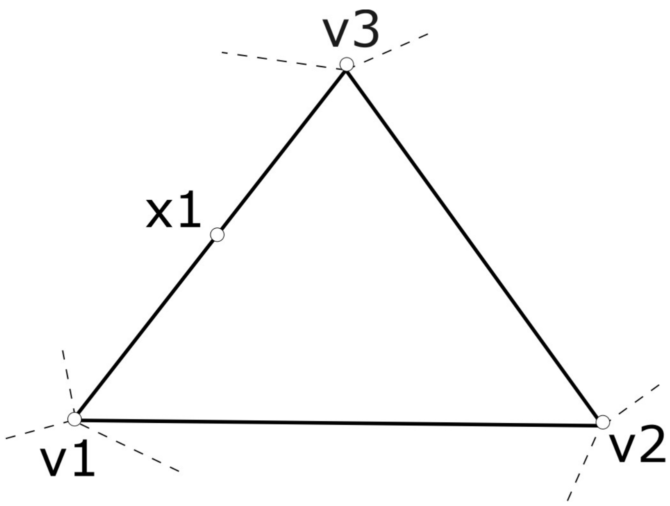


Fig. 1: One highlighted triangle in a triangle mesh.

3 Graphics primitives

Figure 3 shows a 2-simplex (triangle) being part of a polygon mesh. The triangle $\Delta$ is defined by three vertices $v_1, v_2, v_3$. These vertices are connected counter-clockwise with edges.

a For a naïve surface subdivision algorithm it is required to split this triangle into four smaller triangles. For efficiency reasons the smaller triangles have to be arranged using a connected triangle strip.

Draw the triangle from Figure 3 in your answer book and sketch a subdivision strategy that results in an OpenGL triangle strip, *i.e.*, a single connected path, that fully covers the area given by triangle $\Delta$. Clearly enumerate your steps in the sketch, start the triangle strip at $v1$ and indicate the direction of your path with arrows.

b Point coordinates can be defined based on the triangle in Figure 3 in various ways.

i) Name two common strategies to characterise point coordinates relative to a triangle.

ii) What's the difference between these two strategies?

iii) Show a simple way to convert between both.

iv) What's the biggest advantage of point coordinates defined relative to a triangle?

c The coordinates of the vertices $v_1, v_2, v_3$ in *Cartesian* coordinates are: $v_1 = (0,0,0)$ $v_2 = (2,0,0)$ $v_3 = (2,2,0)$.

Convert $v_1$, $v_2$, $v_3$ to Barycentric coordinates. Another point is given in *Cartesian* coordinates as $x1 = (1,1,0)$. Convert this point into Barycentric coordinates relative to $\Delta$. Show your calculation.

d Is $p_c = (1,2,0)$ (*Cartesian* coordinates) contained inside $\Delta$ when orthographically projecting both on the $xy$-plane? Justify your answer. What's the Distance of $p$ to the Centroid of $\Delta$ in Barycentric coordinates?

e How can Barycentric coordinates be used for linear interpolation during triangle rasterization? Show an example interpolating a normal vector for $x1$ using Barycentric coordinates. The normal vectors at the vertices are $v1_n = (-1,0,0)$ and $v1_n = (0,1,0)$

f Outline a simple triangle subdivision algorithm that allows splits into arbitrary numbers of sub-triangles in pseudo code. Do not forget to show the necessary steps for correct colour and normal-vector interpolation of newly generated vertices.

*The six parts carry, respectively, 20%, 20%, 20%, 10%, 10%, and 20% of the marks.*

4 Transformations

a You are asked to implement view point changes for a visualisation company. The model-matrix (the position and orientation) for a CGI object is described by a translation matrix, $T$, and a rotation matrix, $R$, as given below.

$$\mathbf{M} = \mathbf{TR} = \begin{pmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} r_{xx} & r_{yx} & r_{zx} & 0 \\ r_{xy} & r_{yy} & r_{zy} & 0 \\ r_{xz} & r_{yz} & r_{zz} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

i) When the user presses a key, the object should move $x$ units in the world-space z direction. How would you modify the translation matrix?

ii) How would you modify the rotation matrix for the object to turn slightly to the right around $r_y$?

iii) When the user presses the "up-arrow" key, the object shall move forward in the direction it is facing. How do you modify the matrices?

iv) The user wants a view from inside the object. Show a simple calculation that yields a matrix that would achieve this?

b Suppose we would like to mirror an object across a plane $ax + by + cz + d = 0$. In a specific case the plane is defined by $a = 0$, $b = 1$, $c = 0$, $d = y_0$. Write down the transformation matrix which achieves this mirror reflection for this specific case.

c Suppose we look at a unit cube from the point $(0, 0, -6)$ in the direction $(0, 0, 1)$. The unit cube has corners at (0, 0, 0), (0, 0, 1), (0, 1, 0), (1, 0, 0), (0, 1, 1), (1, 1, 0), (1, 0, 1), (1, 1, 1). The scene is to be drawn in perspective projection and the plane of projection is z = -3.

i) What homogeneous transformation matrix achieves this projection?

ii) Sketch what the picture will look like. You may assume there are no clipping planes.

d Name the type of transformation that is defined by the following $4 \times 4$ matrices. Please write in your answer book e.g. i) $\mathbf{M}_1$ = ...

i) $\mathbf{M}_1 = \begin{pmatrix} 5 & 0 & 0 & 0 \\ 0 & 5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

ii) $\mathbf{M}_2 = \begin{pmatrix} 1 & 42 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

iii) $\mathbf{M}_3 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$

iv) $\mathbf{M}_4 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -42 \\ 0 & 0 & 1 & 0 \end{pmatrix}$

*The four parts carry, respectively, 40%, 20%, 20%, and 20% of the marks.*