UNIVERSITY OF OTAGO EXAMINATIONS 2016

COMPUTER SCIENCE

Paper COSC342

Computer Graphics

Semester 1

(TIME ALLOWED: THREE HOURS)

This examination comprises 6 pages.

Candidates should answer questions as follows:

Candidates must answer **all** questions.
Questions are worth various marks, and marks are shown thus: (5)
The total number of marks available for this examination is 60.
You should keep your answers short.
In general, if there are two marks for an answer, you should have two things to say.

The following material is provided:

Nil.

Use of calculators:

No calculators are permitted.

Candidates are permitted copies of:

Nil.

1. Compression is often used to reduce the size of image files.

   (a) What is the difference between *lossy* and *lossless compression*? (1)

   (b) GIF image files use a palette of up to 256 colours, and each pixel's colour is stored as an index into this palette. This is then followed by lossless compression based on finding common patterns of pixel values in the image.

      (i) Explain why the use of a palette makes GIF, in general, a *lossy* compression method. (1)

      (ii) Give an example where GIF would be a *lossless* compression method. (1)

2. The following questions refer to the image (left), with greyscale pixel values, and the filter kernel (right) shown below.

8	7	6	4	1
9	7	5	3	1
7	5	2	2	1
7	6	4	2	1
9	9	5	4	4

G=

0	1/8	0
1/8	1/2	1/8
0	1/8	0

   (a) Show how the result of this filter is computed when it is applied to the central pixel of the image. (3)

   (b) The filter G is an approximation to a *Gaussian filter*, which has the general form

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{-(x^2+y^2)}{2\sigma^2}}.$$

      (i) What is the general effect of a Gaussian filter when applied to an image? (1)

      (ii) How does the effect of a Gaussian filter change as σ increases? (1)

3. Given an image where the boundary pixels of a polygon have been painted, *flood fill* is one approach to painting the inside of a polygon. Here is one version of the flood fill algorithm:

```
floodFill(Point p) {
  Stack S
  paint(p)
  S.push(p)
  while (!S.empty()) {
    q = S.pop()
    for each neighbour, r, of q {
      if (!painted(r)) {
        paint(r)
        S.push(r)
      }
    }
  }
}
```

(a) This version of flood fill uses a stack, but a queue is often preferred in practice. Explain why. (2)

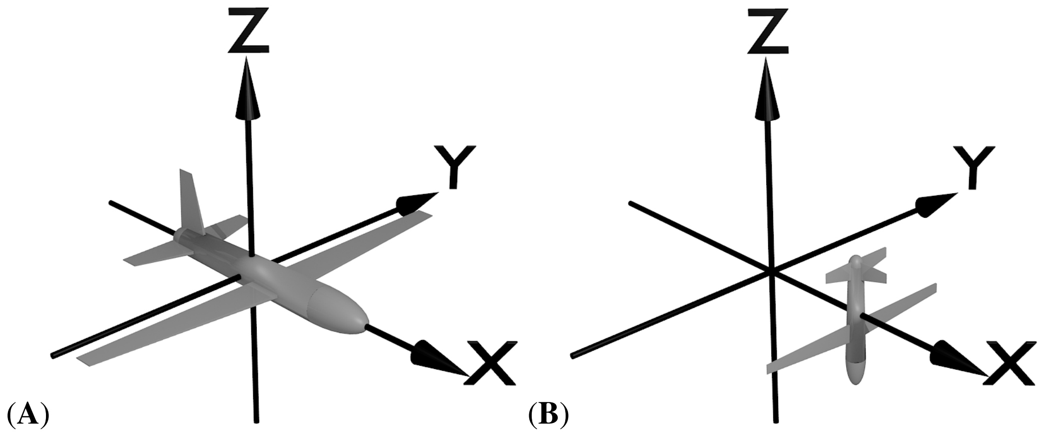
(b) An alternative approach is a *scanline fill*. Explain how scanline filling works. (4)

4. When working with points in 2D and 3D it is often convenient to use *homogenous* co-ordinates.

(a) What is the homogeneous form of a 3D point, (x, y, z)? (1)

(b) What is the main advantage of homogeneous co-ordinates? (1)

5. The images below show a model of an aeroplane before (**A**) and after (**B**) a transformation.



(a) Describe the rotation and scaling necessary to transform the aeroplane from (**A**) to (**B**). The transformed aeroplane is half the size of the original and moved 1 unit along the X-axis. (3)

(b) Write down the homogenous matrices that represent these operations. (3)

(c) In what order should these matrices be applied in order to transform a 3D point, $\mathbf{p}$, represented in homogeneous form? (1)

6. Images in a mosaic are related by a *homography*. In order to estimate a homography it is necessary to establish a correspondence between feature points in two images.

(a) Simple feature matching might use the pixel values in a small window around a feature point to describe the features. This approach is not robust to changes in scale, illumination, and rotation. Explain how SIFT features overcome these limitations. (3)

(b) When automatically matching features between images it is common for incorrect (or outlier) matches to be made. Briefly explain how RANSAC can be used to overcome this problem when computing a homography for mosaicing. (4)

7. Consider a scene containing a sphere with radius 1 that is centred at the origin. The ray equation is defined as usual: $\mathbf{p}(t) = \mathbf{u} + t\mathbf{v}$.

You may solve the questions below using geometry and intuition, provided that you show your working. If you instead wish to work algebraically, again showing your working, the quadratic formula set up to solve for t is provided here for your reference.

$$t = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

where:

$$\begin{aligned} A &= \mathbf{v}^2 \\ B &= 2\mathbf{u} \cdot \mathbf{v} \\ C &= \mathbf{u}^2 - 1.0 \end{aligned}$$

(a) Assuming that $\mathbf{u} = \begin{bmatrix}0 & 0 & -2\end{bmatrix}^\mathsf{T}$ and $\mathbf{v} = \begin{bmatrix}0 & 0 & 1\end{bmatrix}^\mathsf{T}$, what are all the t values for the intersection with the sphere? What is the location of the hitpoint in 3D coordinates? (3)

(b) Now let $\mathbf{u} = \begin{bmatrix}0 & 0 & 0\end{bmatrix}^\mathsf{T}$ and $\mathbf{v} = \begin{bmatrix}0 & 1 & 0\end{bmatrix}^\mathsf{T}$. What are all the t values for the intersection with the sphere now? Explain the geometric meaning of each t value that you find. (3)

8. A scene contains an infinite plane that extends in the XY plane, and contains the origin. Consider a primary ray $\mathbf{p}(t) = \mathbf{u} + t\mathbf{v}$ with $\mathbf{u} = \begin{bmatrix}-1 & 0 & 1\end{bmatrix}^\mathsf{T}$ and $\mathbf{v} = \begin{bmatrix}0 & -1 & -1\end{bmatrix}^\mathsf{T}$.

(a) What is the location in 3D of the hitpoint on the plane, and what is the normal vector at that point? (2)

(b) Assuming that the plane's material provides mirror reflections, what is the mirror ray at the hitpoint? You should be able to determine your answer by sketching the scene and thinking spatially. (2)

9. In lectures we derived the following local illumination model:

$$I_{total} = I_a k_a + I_j \left(k_d(\hat{\boldsymbol{\ell}}_j \cdot \hat{\mathbf{n}}) + k_s(\hat{\mathbf{e}} \cdot \hat{\mathbf{r}}_j)^n \right)$$

Consider a hitpoint on a surface within a scene that has normal vector $\mathbf{n} = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}^{\mathsf{T}}$.

(a) Give the vector from the hitpoint to a point lightsource, that will maximise the intensity of the diffuse lighting term $k_d(\hat{\boldsymbol{\ell}}_j \cdot \hat{\mathbf{n}})$. Briefly explain how you reached this answer. You can ignore attenuation (*i.e.* diminishing) of the intensity of the lightsource due to distance. (2)

(b) For the same hitpoint, normal and lightsource position, how can you set up the scene to simultaneously maximise the specular component $k_s(\hat{\mathbf{e}} \cdot \hat{\mathbf{r}}_j)^n$ as well? (2)

10. For a uv coordinate space of a texture, where u and v both range from 0 to 1, the texture is a black background, with a white triangle superimposed over it. In uv coordinates, the vertices of the triangle are at $\begin{bmatrix} 0 & 0 \end{bmatrix}^{\mathsf{T}}$, $\begin{bmatrix} 1 & 0 \end{bmatrix}^{\mathsf{T}}$ and $\begin{bmatrix} 0 & 1 \end{bmatrix}^{\mathsf{T}}$

(a) Sketch the texture. (1)

(b) The texture is applied in a repeating pattern to an infinite plane. What colour should the pixels on the plane close to the horizon be? Why? (2)

(c) What colour will the pixels on the plane near the horizon actually be if a single ray is cast per pixel? (2)

(d) Describe a technique that can help address the above problem. (2)

11. Consider two spheres s_1 and s_2 being combined using constructive solid geometry (CSG). Both spheres are centred on the origin. Sphere s_1 is blue and sphere s_2 is red. Sphere s_2 is subtracted from sphere s_1.

(a) If s_1 has radius 1, and s_2 has radius 2, describe the result. (1)

(b) Instead, if s_1 has radius 2, and s_2 has radius 1, then describe the result. Is it possible to end up with a red hit point? (2)

(c) What happens in theory and in practice when both s_1 and s_2 have radius 1? (2)

12. A scene contains an infinite XY plane that includes the origin, and a sphere of unit radius with centre $\begin{bmatrix} 0 & 0 & 2 \end{bmatrix}^{\mathsf{T}}$. The scene is illuminated by a direction light (*i.e.*, the light vector is constant, and the light does not diminish over distance) that shines in direction $\begin{bmatrix} 0 & 0 & -1 \end{bmatrix}^{\mathsf{T}}$. We will render the scene with a raytracer that is similar in capabilities to the raytracer built in the second assignment.

(a) Consider the sphere to be made of black coal. Describe the shape of the shadow that is cast on the plane. (1)

(b) Now instead consider the sphere to be made of glass. How does this change the shadow? Describe a technique that would produce a more realistic shadow. (3)

END