

**Question One (20 Marks)**

- a) In relation to computer graphics, define the following terms (6 marks)
- Graphics** are visual representations on some surface, such as a wall, canvas, computer screen, paper, or stone to brand, inform, illustrate, or entertain
  - Graphic design** consists of the deliberate selection, creation, or arrangement of typography, as in a brochure, flier, poster, web site, or book
  - A **digital image** is a representation of a two-dimensional image in binary format as a sequence of ones and zeros.

**(2 marks each for correct definition)**

- b) Explain the key differences between a Raster Scan display and a Random scan display (2 marks)
- Raster scan system refreshes all pixels during each scan cycle
  - Random scan system only addresses changes to specific pixels of an image per scan cycle
- (1 mark for each)**

- c) Identify the major difference between the two-dimensional and three-dimensional viewing pipelines (2 marks)
- 2D viewing pipeline– clipping is done at the viewing transformation stage. Has no transformation projection
- 3D viewing pipeline – clipping definition is done at viewing transformation stage, to be executed at normalization stage. Has a projection transformation.

**(1 mark for each difference)**

- d) Explain how the interactive graphics pipeline is implemented in hardware (3 marks)
- The rendering pipeline is mapped onto current graphics acceleration hardware such that the input to the graphics card (GPU) is in the form of vertices.
  - These vertices then undergo transformation and per-vertex lighting. At this point in modern GPU pipelines a custom vertex shader program can be used to manipulate the 3D vertices prior to rasterization.

- Once transformed and lit, the vertices undergo clipping and rasterization resulting in fragments. A second custom shader program can then be run on each fragment before the final pixel values are output to the frame buffer for display.

- e) State and briefly explain any 4 advantages of vector graphics over raster graphics  
(4 marks)

The following are the most important advantages of vector graphics:

- **Complete scalability** - you can resize vector graphics without any loss in quality. Whether you're designing a business card or very large advertising poster, the quality stays the same
- **Usability for both web and print** - while bitmap graphics is printable only if its graphical resolution is 300 dpi or higher, vector graphics is always printer friendly.
- **Vector graphics is completely editable** - you can resize, skew, rotate and reshape it, combine it with another vector objects, weld and trim them, color it etc.
- **Background transparency** - it will match any background, any color and/or pattern, any other bitmap or vector graphics.

(Any 4 well explained points = 1 mk @)

- f) Using examples, discuss 3 ways in which 3D illusions are created in computer graphics  
(3 marks)

- **Monoscopic Depth Cues** E.g. Interposition: An object that occludes another is closer
- **Stereoscopic Depth Cues**: Stereoscopic display systems create a three-dimensional image (versus a perspective image) by presenting each eye with a slightly different view of a scene.
- **Motion Depth Cues**: Objects nearer to the eye move a greater distance
- **Physiological Depth Cues**: focusing adjustment made by the eye to change the *shape* of the lens.

(Any 3 well explained ideas = 1 mk @)

**Question Two (15 Marks)**

- a) Explain the following terms as used in color representation (3 marks)
- i. Hue  
The term for the pure spectrum colors commonly referred to by the color names; red, orange, yellow, blue, green, violet which appear in the hue circle or rainbow. (1 mark)
  - ii. Lightness  
Property of a color or a dimension of color space, that is defined in a way to reflect the subjective brightness perception of a color for humans along a lightness-darkness axis. (1 mark)
  - iii. Saturation: Degree to which a color is mixed with white, high saturation means little white while low saturation means more white. (1 mark)
- b) Distinguish between modeling and rendering as used in computer graphics (2 marks)
- Modeling:** producing a precise description of a scene (model), in terms of graphics primitives.
- Rendering:** producing an image based on the model. Images are produced in a framebuffer.
- c) A point  $P(5,10,7)$  which is a part of a larger object is to be rotated through an angle of 45 degrees anti-clockwise, then uniform scaled by a factor  $S$  of 3. Compute the combined homogeneous transformation matrix (4 marks)

- d) Compute the final coordinates for the point P in (c) above (2 marks)
- e) Explain why perspective transformations are more preferable to parallel transformations. (3 marks)
- visual effect is similar to human visual system...
  - has 'perspective foreshortening'
    - size of object varies inversely with distance from the center of projection.
  - angles only remain intact for faces parallel to projection plane.
  - In the real world, objects exhibit *perspective foreshortening*: distant objects appear smaller

**(1 mk for @ pt)**

### Question Three (15 Marks)

- a) Define the following terms as used in display systems (4 marks)
- i. **Vertical Sync Pulse:** Signals the start of the next field
  - ii. **Vertical Retrace:** Time needed to get from the bottom of the current field to the top of the next field
  - iii. **Horizontal Sync Pulse:** Signals the start of the new scan line
  - iv. **Horizontal Retrace:** The time needed to get from the end of the current scan line to the start of the next scan line

- b) Explain the advantage of Bresenham Line algorithm over Digital Differential Analyzer algorithm (2 marks)
- Is an incremental algorithm that uses only integer calculations make the process very fast

- c) Explain the meaning of critical fusion frequency in display systems (2 marks)

The minimum frequency at which the pixels must be refreshed to sustain an image on the display

(2 mks for correct ans)

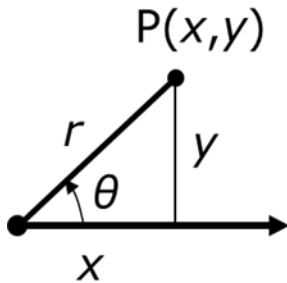
- d) Distinguish between dedicated and integrated graphics cards (4 marks)

#### Dedicated graphics cards

- A dedicated GPU is not necessarily removable, nor does it necessarily interface with the motherboard in a standard fashion.
- The term "dedicated" refers to the fact that dedicated graphics cards have RAM that is dedicated to the card's use, not to the fact that *most* dedicated GPUs are removable.
- **Integrated graphics processors (IGP)** utilize a portion of a computer's system RAM rather than dedicated graphics memory. They are integrated into the motherboard with few exceptions

(2 mks @ for correct ans)

- e) Assuming the point P in the diagram below has the coordinates (3,5), derive the polar coordinates for P (3 marks)



Use the equations

$$\begin{aligned} x &= r \cos(\theta) \\ y &= r \sin(\theta) \end{aligned}$$

$$\begin{aligned} r^2 &= x^2 + y^2 \\ \tan(\theta) &= y/x \end{aligned}$$

#### Question Four (15 Marks)

- a) Discuss the motivating factors for surface modeling (3 marks)

Many real-world objects are inherently smooth, therefore need infinitely many points to model it. This is not feasible for a computer with finite storage. More often we merely approximate the object with pieces of planes, spheres, or other shapes that are easy to describe mathematically.

**(3 mks for correct ans)**

- b) Using illustrations, describe the following techniques used in representing polygon meshes (4 marks)

- i. Pointer to a vertex list: store all vertices once into a numbered list, and represent each polygon by its vertices. It saves space (vertex only listed once) but still has no explicit representation of shared edges and vertices

Such as

$$P = (1,3,4,5)$$

- ii. Explicit edges: list all edges that belong to a polygon, and for each edge list the vertices that define it along with the polygons of which it is a member. Such as

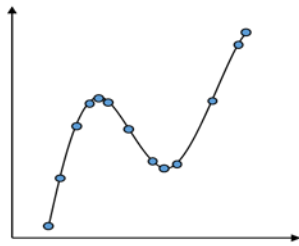
$$E = (V_1, V_2, P_1)$$

- c) Using examples and illustrations, explain the 2 common techniques for specifying curves in surface modeling (4 marks)

### Specifying Curves

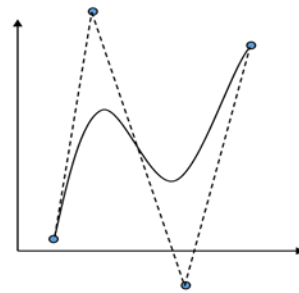
- **Control Points**

control points that lie on the curve



- **Interpolating spline**

curve passes through the control points knots (*Cardinal spline, Catmull-Rom spline*)



- **Approximating spline**

control points merely influence shape (*Hermite Curves, B-spline*)

- f) Describe the image space approach to visible surface determination. Hence give the pseudo code for the z-buffer image space algorithm (4 marks)

- Image space algorithms do their work as the objects are being converted to pixels in the frame buffer. The resolution of the display device is important here as this is done on a pixel by pixel basis.

- **Pseudo code...**

for each polygon for each pixel  $p$  in the polygon's projection

```

{
  pz = polygon's normalized z-value at (x, y);
  //z ranges from -1 to 0
  if (pz > zBuffer[x, y]) // closer to the camera
  {
    zBuffer[x, y] = pz;
  }
}

```

```

        framebuffer[x, y] = colour of pixel p;
    }
}

```

### Question 5 (15 Marks)

- a) Describe the principles of the brute-force line clipping algorithm. State its limitation and discuss the solution offered by the Cohen Sutherland algorithm

(2 marks)

#### Brute force approach

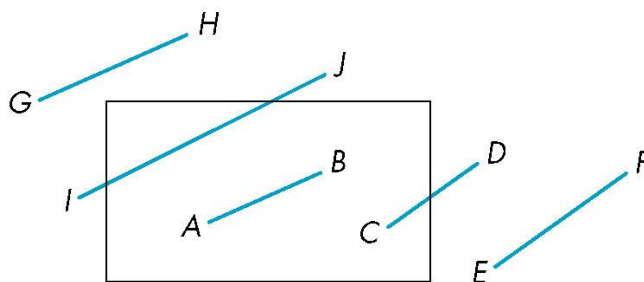
- Computes intersections with all sides of clipping window. Inefficient: one division per intersection

#### CS:

- Idea: eliminate as many cases as possible without computing intersections by using outcodes for the various regions of the viewport

- b) Explain the process of clipping the line EF in the diagram below using the Cohen Sutherland Line Clipping algorithm

(3 marks)



- EF: outcode(E) logically ANDed with outcode(F) (bitwise)  $\neq 0$ 
  - Both outcodes have a 1 bit in the same place
  - Line segment is outside of corresponding side of clipping window



○ reject

- c) Compute the values of  $p_i$  and hence generate the coordinates for a line starting at pixel (2,3) and ending at pixel (12,8) using the Bresenham algorithm (5 marks)

t	p	P(x)	P(y)
0	0	2	3
1	-10	3	4
2	0	4	4
3	-10	5	5
4	0	6	5
5	-10	7	6
6	0	8	6
7	-10	9	7
8	0	10	7
9	-10	11	8
10	0	12	8

- d) A point  $P(5,10)$  which is part of a larger image is to be transformed from a window measuring  $500 \times 1000$  to a viewport measuring  $350 \times 800$ . Compute the new coordinates of  $P$  (5 marks)

### Question one

- g) Describe any four tasks of a graphics processor that relate to computer graphics (6 marks)
- Transformation
  - Clipping
  - Projection
  - Shading and coloring
  - Texturing
  - Hidden surface removal
- (a description of any 4, 2 marks each)
- h) Explain the key differences between a Raster Scan display and a Random scan display (4 marks)
- Raster scan system refreshes all pixels during each scan cycle
  - Random scan system only addresses changes to specific pixels of an image per scan cycle (2 marks for each)
- i) Identify the major difference between the two-dimensional and three-dimensional viewing pipelines (4 marks)
- 2D viewing pipeline– clipping is done at the viewing transformation stage. Has no transformation projection
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- (1 mark for each difference)
- j) Explain the following components as used in computer graphics
- Focusing system  
Focus the electron beam to converge to a small spot as it strikes the phosphor coated screen. (2 marks)
  - Deflection system  
Controls the deflection of the electron beam for it to strike at a specific position on the screen (2 marks)

## iii. Electron gun

Emits a beam of electrons which are negatively charged and are directed to the phosphor coated screen by a high positive voltage (2 marks)

k) Describe any 2 major display technologies as used in computer graphics (10 marks)

- Cathode Ray Tube (CRT)
- Liquid Crystal Display (LCD)
- Plasma displays
- OLED

A brief description of any 2 of the above, 5 marks each, a total of 10 marks

**Question two**

a) Briefly describe the Mid-Point Circle Algorithm, highlighting the significance of symmetry to the algorithm (8 marks)

## MID-POINT CIRCLE ALGORITHM

1. Input radius  $r$  and circle centre  $(x_c, y_c)$ , then set the coordinates for the first point on the circumference of a circle centred on the origin as:

$$(x_0, y_0) = (0, r)$$

2. Calculate the initial value of the decision parameter as:

$$p_0 = \frac{5}{4} - r$$

3. Starting with  $k = 0$  at each position  $x_k$ , perform the following test. If  $p_k < 0$ , the next point along the circle centred on  $(0, 0)$  is  $(x_{k+1}, y_k)$  and:

$$p_{k+1} = p_k + 2x_{k+1} + 1$$

Otherwise the next point along the circle is  $(x_{k+1}, y_{k-1})$  and:

$$p_{k+1} = p_k + 2x_{k+1} + 1 - 2y_{k+1}$$

4. Determine symmetry points in the other seven octants
5. Move each calculated pixel position  $(x, y)$  onto the circular path centred at  $(x_c, y_c)$  to plot the coordinate values:

6. Repeat steps 3 to 5 until  $x \geq y$

- b) Distinguish between the following camera control terms;
- i. Circle of confusion  
The projection of a point at a position on the image plane forming an approximate circle – makes it unclear where the point is precisely located (2 marks)
  - ii. Depth of the field  
Choice of a camera position such that the size of the circle of confusion for a range of distances is minimized. (2 marks)
- c) Identify two basic terms that describe a camera scene (2 marks)
- i. Camera position – where the camera is positioned
  - ii. Camera orientation – determines the projection angle (1 mark each)
- d) Describe the purpose of the following techniques as used in creating 3-Dimensional sceneries;
- i. Parallel projection  
Projecting points of a 3D object on the object surface along parallel line. This is used especially to show accurate dimensions. (2 marks)
  - ii. Perspective projection  
A method of generating a more realistic view of a 3D view by projecting points to the display plane along converging lines (2 marks)
  - iii. Depth cueing  
A method used in graphics to capture depth information to help the viewer identify the particular viewing directions i.e. back to front. (2 marks)

**Question three**

- f) Briefly describe how to generate line using Bresenham Line Algorithm (7 marks)

**BRESENHAM'S LINE DRAWING ALGORITHM**(for  $|m| < 1.0$ )

1. Input the two line end-points, storing the left end-point in  $(x_0, y_0)$
2. Plot the point  $(x_0, y_0)$
3. Calculate the constants  $\Delta x$ ,  $\Delta y$ ,  $2\Delta y$ , and  $(2\Delta y - 2\Delta x)$  and get the first value for the decision parameter as:

$$p_0 = 2\Delta y - \Delta x$$

4. At each  $x_k$  along the line, starting at  $k = 0$ , perform the following test. If  $p_k < 0$ , the next point to plot is  $(x_k + 1, y_k)$  and:

$$p_{k+1} = p_k + 2\Delta y$$

Otherwise, the next point to plot is  $(x_k+1, y_k+1)$  and:

$$p_{k+1} = p_k + 2\Delta y - 2\Delta x$$

5. Repeat step 4  $(\Delta x - 1)$  times

(1 mark for each step)

- g) Explain any two advantages of Bresenham Line Algorithm over Digital Differential Analyzer Algorithm (4 marks)
- Is a fast incremental algorithm
  - Uses only integer calculations
- h) Describe two approaches to generate images on the screen (6 marks)
- i. Stroke writing
  - ii. Raster display
- (A description of the above, 3 marks each)
- i) Describe aliasing as used in computer graphics? (3 marks)
- Aliasing is a signal processing term. It occurs when a system is measured at an insufficient sampling rate.

#### Question four

- b) Explain the purpose of the following procedures in 3-Dimensional Modeling;
- i. Surface rendering  
Use of lighting conditions in a scene and the assigned surface characteristics to add realism to a view (2 marks)
  - ii. Stereoscopic views  
This is applied together with stereoscopic devices. Such devices present two views of a scene, one for each eye. The views correspond to the eye positions of the viewer, and result in a 3D effect. (2 marks)

- c) Describe clipping and outline any three trivial tests that can be performed during line clipping (5 marks)

Clipping is removal of points that are outside the region of interest i.e. clip-window. (2 marks)

Trivial tests:

- i. The line segment is entirely inside (keep it)
  - ii. The line segment is entirely outside (discard it)
  - iii. The line segment is partially inside and partially outside (generate new line to represent part inside) (1 mark each)
- d) Explain the following terms as used in color representation?
- i. Hue  
The term for the pure spectrum colors commonly referred to by the color names; red, orange, yellow, blue, green, violet which appear in the hue circle or rainbow. (1 mark)
  - ii. Lightness  
Property of a color or a dimension of color space, that is defined in a way to reflect the subjective brightness perception of a color for humans along a lightness-darkness axis. (1 mark)
  - iii. Saturation  
Degree to which a color is mixed with white, high saturation means little white while low saturation means more white. (1 mark)

### Question 5

- a) Discuss the principles of rigid body and affine transformations (3 marks)

– A transformation matrix of the form

$$\begin{bmatrix} r_{11} & r_{12} & t_x \\ r_{21} & r_{22} & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

- where the upper  $2 \times 2$  sub-matrix is orthogonal, preserves angles and lengths. Such transforms are called **rigid-body** transformations, because the body or object being transformed is not distorted in any way. An arbitrary sequence of rotation and translation matrices creates a matrix of this form.

- The product of an arbitrary sequence of rotation, translations, **and scale** matrices will cause an **affine** transformation, which have the property of preserving parallelism of lines, but not of lengths and angles.

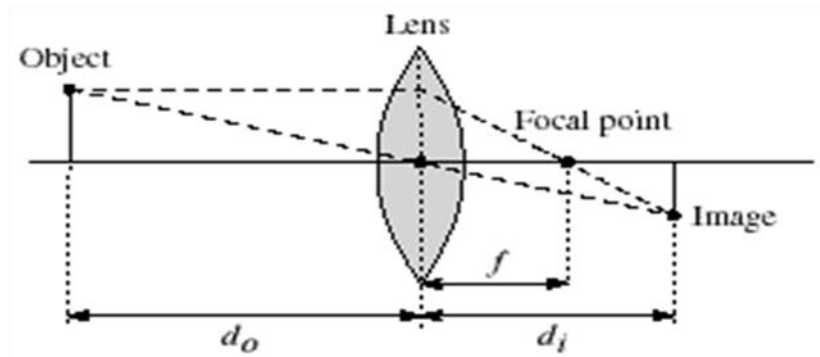
b) Describe the 'Pulfrich Effect' and state its relevance in computer graphics

(2 marks)

- Different levels of illumination require additional time (your frame rates differ base of amount of light)
- What if we darken one image, and brighten another?
- Useful in developing 2D to 3D cues

c) Explain how focus is obtained in a thin lens camera model

(5 marks)



- Thin lens equation:  $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$

- Any object point satisfying this equation is in focus

d) Discuss the process of transforming an object from the world coordinates (WC) space to the viewing coordinates (VC) space

(5 marks)

- Transformation sequences

- Translate the view reference point to the origin of the WC system
  - o view reference point( $x_0, y_0, z_0$ )

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & -x_0 \\ 0 & 1 & 0 & -y_0 \\ 0 & 0 & 1 & -z_0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Apply rotations to align the  $x_v, y_v,$  and  $z_v$  axes with the
  - o rotate around the world  $x_w$  axis to bring  $z_v$  into the  $x_w z_w$  plane
  - o rotate around the world  $y_w$  axis to align the  $z_w$  and  $z_v$  axis
  - o final rotation is about the  $z_w$  axis to align the  $y_w$  and  $y_v$  axis