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**CS-112: Introduction to Computer Graphics**  
**Midterm - Winter 2020**  
**02/11/2020**

**Total Time:** 120 min

**Total Points:** 120

**Name:** \_\_\_\_\_

Pledge: I neither received nor gave any help from or to anyone in this exam.

**Signature:** \_\_\_\_\_

**Useful Tips**

1. All questions are multiple choice questions --- please indicate your answers very clearly. **Please circle your choice clearly.**
2. **Some questions have more than one answer. Full credit is given for marking all the correct answers.**
3. Use the blank pages as your worksheet. Put the question number when working out the steps in the worksheet. Also, do your work clearly. This will help us give partial credit.
4. If you need more work sheets, feel free to ask for extra sheets.
5. Staple all your worksheets together with the paper at the end of the exam. If pages of your exam are missing since you took them apart, we are not responsible for putting them together.
6. **The number of minutes you should spend on each question is roughly equal to the number of points assigned to the question.**

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1) [2+3+3+2=10] Consider a 2D rectangle **ABCD** where  $A=(0,0)$ ,  $B=(2,0)$ ,  $C=(2,1)$  and  $D=(0,1)$ . We want to apply a 2D transformation to this rectangle which makes it a parallelepiped **ABEF** where  $E=(3,1)$  and  $F=(1,1)$ .

- a. What kind of transformation is this?
  - i. Scale
  - ii. Rotate
  - iii. Shear
  - iv. Translate
  
- b. The 3x3 matrix **M** achieving this transformation is given by
  - i.  $[1 \ 1 \ 0 ; 0 \ 1 \ 0 ; 0 \ 0 \ 1]$
  - ii.  $[1 \ 0 \ 0 ; 1 \ 1 \ 0 ; 0 \ 0 \ 1]$
  - iii.  $[1 \ 0 \ 1 ; 0 \ 1 \ 0 ; 0 \ 0 \ 1]$
  - iv.  $[1 \ 0 \ 0 ; 0 \ 1 \ 0 ; 1 \ 0 \ 1]$
  
- c. What additional transformation **N** we would need to apply to **ABEF** to get the parallelepiped **A'B'E'F'**, where  $A'=(2,1)$ ,  $B'=(4,1)$ ,  $E'=(5,2)$ , and  $F'=(3,2)$ ?
  - i. Rotation by  $45^\circ$
  - ii. Scale by  $(2,1)$
  - iii. Translate by  $(2,1)$
  
- d. What is the final concatenated matrix in terms of **M** and **N** that will transform **ABCD** to **A'B'E'F'**?
  - i. **MN**
  - ii. **NM**
  - iii.  **$M^{-1}N$**
  - iv.  **$N^{-1}M$**

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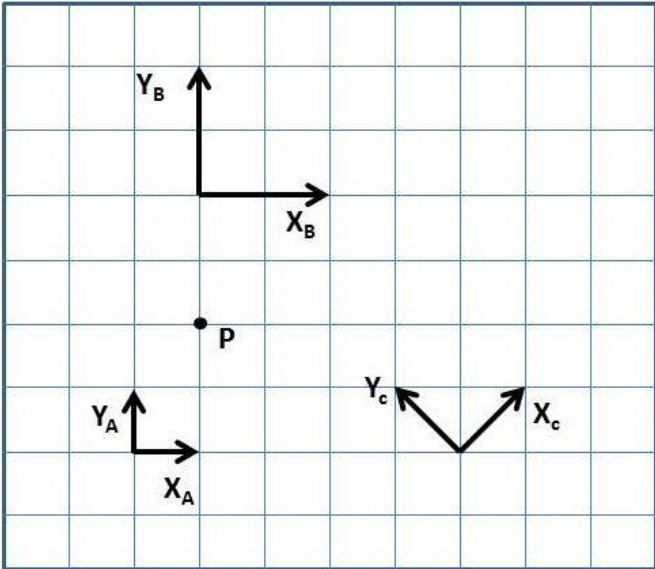
2) [3+2=5] Consider the following matrix (Note:  $1/\sqrt{2} = 0.707$ ).

$$\begin{bmatrix} 0.707 & 0.707 & 0 & 0 \\ -0.707 & 0.707 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- a. This matrix achieves the following in the *global coordinate system*:
- i.  $R_z$  of  $45^\circ$  followed by  $S_z$  of 2
  - ii.  $R_y$  of  $45^\circ$  following by  $S_z$  of 2
  - iii.  $S_z$  of 2 followed by  $R_z$  of  $45^\circ$
  - iv.  $S_z$  of 2 followed by  $R_y$  of  $45^\circ$
- b. Consider a translation  $T$  of the *local coordinate system* following these transformations. The resultant transformation will be:
- i.  $R_y S_y T$
  - ii.  $T R_y S_y$
  - iii.  $T S_y R_y$
  - iv.  $S_y R_y T$

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**3) [1+1+2+3+4+4=15]** Consider the point P and the three different coordinate axes, A, B and C.



- a.** What is the coordinate of P in coordinate system A?
- i.** (2, 1)
  - ii.** (1, 2)
  - iii.** (0, -2)
  - iv.** (-2, 0)
  - v.**  $(-\sqrt{2}, 3\sqrt{2})$
  - vi.**  $(3\sqrt{2}, -\sqrt{2})$
- b.** What is the coordinate of P in coordinate system B?
- i.** (2, 1)
  - ii.** (1, 2)
  - iii.** (0, -2)
  - iv.** (-2, 0)
  - v.**  $(-\sqrt{2}, 3\sqrt{2})$
  - vi.**  $(3\sqrt{2}, -\sqrt{2})$
- c.** What is the coordinate of P in coordinate system C?
- i.** (2, 1)
  - ii.** (1, 2)
  - iii.** (0, -2)
  - iv.** (-2, 0)
  - v.**  $(-\sqrt{2}, 3\sqrt{2})$
  - vi.**  $(3\sqrt{2}, -\sqrt{2})$

**Question-3 continues to the next page**

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**d.** The 3x3 matrix to convert from homogeneous coordinates in coordinate system A to those in coordinate system B is given by

- i.**  $[1 \ 0 \ 0 ; 0 \ 1 \ 0 ; 1 \ 4 \ 1]$
- ii.**  $[1 \ 0 \ 1 ; 0 \ 1 \ 4 ; 0 \ 0 \ 1]$
- iii.**  $[1 \ 0 \ 0 ; 0 \ 1 \ 0 ; -1 \ -4 \ 1]$
- iv.**  $[1 \ 0 \ -1 ; 0 \ 1 \ -4 ; 0 \ 0 \ 1]$

**e.** The 3x3 matrix to convert from homogeneous coordinates in coordinate system C to those in coordinate system A is given by

- i.**  $[1/\sqrt{2} \ -1/\sqrt{2} \ 5 ; 1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; 0 \ 0 \ 1]$
- ii.**  $[1/\sqrt{2} \ 1/\sqrt{2} \ -5/\sqrt{2} ; -1/\sqrt{2} \ 1/\sqrt{2} \ 5/\sqrt{2}; 0 \ 0 \ 1]$
- iii.**  $[1/\sqrt{2} \ -1/\sqrt{2} \ 0 ; 1/\sqrt{2} \ 1/\sqrt{2} \ 0; 5 \ 0 \ 1]$
- iv.**  $[1/\sqrt{2} \ -1/\sqrt{2} \ -5/\sqrt{2} ; 1/\sqrt{2} \ 1/\sqrt{2} \ 5/\sqrt{2}; 0 \ 0 \ 1]$
- v.**  $[1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; -1/\sqrt{2} \ 1/\sqrt{2} \ 0; -5/\sqrt{2} \ 5/\sqrt{2} \ 1]$

**f.** The 3x3 matrix to convert from homogeneous coordinates in coordinate system A to those in coordinate system C is given by

- i.**  $[1/\sqrt{2} \ -1/\sqrt{2} \ 5 ; 1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; 0 \ 0 \ 1]$
- ii.**  $[1/\sqrt{2} \ 1/\sqrt{2} \ -5/\sqrt{2} ; -1/\sqrt{2} \ 1/\sqrt{2} \ 5/\sqrt{2}; 0 \ 0 \ 1]$
- iii.**  $[1/\sqrt{2} \ 1/\sqrt{2} \ 5 ; -1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; 0 \ 0 \ 1]$
- iv.**  $[1/\sqrt{2} \ -1/\sqrt{2} \ 0 ; 1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; 5 \ 0 \ 1]$
- v.**  $[1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; -1/\sqrt{2} \ 1/\sqrt{2} \ 0 ; -5/\sqrt{2} \ 5/\sqrt{2} \ 1]$

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**4) [2+2+3+2+1=10]** Consider the following view setup. The eye is located at  $(0,0,0)$  and the equation of the image plane is given by  $2x+2y+2z = 6$ .

- a.** What is the distance of the near plane  $n$ ?
  - i.** 12
  - ii.**  $\sqrt{12}$
  - iii.**  $\sqrt{3}$
  - iv.** 3
  
- b.** What is the normal to the image plane  $N$ ?
  - i.**  $(1, 1, 0)$
  - ii.**  $(1, 1, 1)$
  - iii.**  $(0, 1, 0)$
  - iv.**  $(1, 0, 1)$
  
- c.** If the vertical and horizontal field-of-view are 60 and 120 degrees respectively, what is the aspect ratio (ratio of width is to height) of the rendering window?
  - i.**  $\sqrt{3}:1$
  - ii.**  $\sqrt{2}:1$
  - iii.**  $3\sqrt{3}:1$
  - iv.**  $3:1$
  
- d.** The view transformation consists of which of the following transformations.
  - i.** Translation
  - ii.** Scaling
  - iii.** Rotation
  - iv.** Shear
  
- e.** What is the third parameter (other than eye and normal) on which the view transformation depends?
  - i.** View Direction
  - ii.** View Up Vector
  - iii.** Near and far plane
  - iv.** Gaze Direction

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**5) [3+2+2=7]** Consider the default OpenGL view with the near plane (or image plane) at a distance 3. The gaze direction is (2,6) and the size of the window in X and Y direction in which it is centered are 12 and 10 respectively.

- a.** The l, r, t, and b of the view frustum is given by:
  - i.** -4, 8, 11, 1
  - ii.** -5, 5, -6, 6
  - iii.** 0, 12, 0, 10
  - iv.** -2, 6, -4, 6
  
- b.** The transformation required to make this window make the gaze direction coincident with the default OpenGL view direction is:
  - i.** Scaling along X and Y axes
  - ii.** Translate in X and Y direction
  - iii.** Z-Shear
  - iv.** X and Y Shear
  - v.** Rotation about the Z axis
  
- c.** Once the view and gaze directions coincide, the transformation required normalize the X and Y coordinates are given by:
  - i.** Scaling along X and Y axes
  - ii.** Translate in X and Y direction
  - iii.** Z-Shear
  - iv.** X and Y Shear
  - v.** Rotation about the Z axis

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**6) [4+4+3+2+2+3=18]** Consider a gray world with no ambient and specular lighting (only diffuse lighting). The screen coordinates of a triangle  $P_1P_2P_3$  are  $P_1 = (100,100)$ ,  $P_2 = (300,150)$ ,  $P_3 = (200, 200)$ . The gray values at  $P_1$ ,  $P_2$  and  $P_3$  are  $\frac{1}{2}$ ,  $\frac{3}{4}$ , and  $\frac{1}{4}$  respectively. Light is at infinity and its direction and gray color are  $(1,1,1)$  and  $1.0$  respectively. The coefficient of diffuse reflection is  $\frac{1}{2}$ . The normals at  $P_1$ ,  $P_2$  and  $P_3$ , are  $N_1=(0,0,1)$ ,  $N_2=(1,0,0)$  and  $N_3=(0,1,0)$  respectively. (Note: Assume the z coordinates of the three points  $P_1$ ,  $P_2$ , and  $P_3$  to be 0). **No need to normalize the normal**).

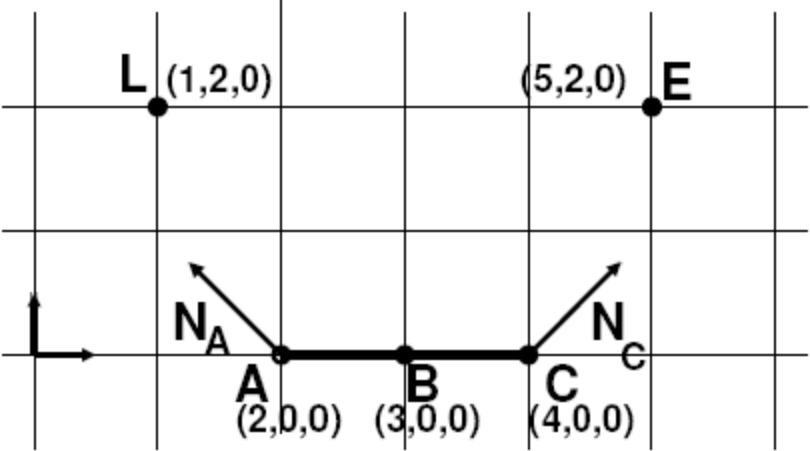
- a. The illumination at the three vertices  $P_1$ ,  $P_2$  and  $P_3$ , are given by:
  - i.  $(\frac{1}{2}, \frac{3}{4}, \frac{1}{4})$
  - ii.  $(\frac{1}{4}, \frac{3}{8}, \frac{1}{8})$
  - iii.  $(\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$
  
- b. The interpolation coefficients of a point P inside the triangle whose coordinates are  $(220,160)$  are given by:
  - i.  $(\frac{2}{5}, \frac{1}{5}, \frac{2}{5})$
  - ii.  $(\frac{1}{4}, \frac{3}{8}, \frac{3}{8})$
  - iii.  $(\frac{1}{5}, \frac{2}{5}, \frac{2}{5})$
  - iv.  $(\frac{1}{4}, \frac{1}{2}, \frac{1}{4})$
  
- c. The illumination at P using Gouraud Shading is:
  - i.  $\frac{15}{32}$
  - ii.  $\frac{1}{4}$
  - iii.  $\frac{9}{40}$
  - iv.  $\frac{1}{2}$
  
- d. The interpolated normal at P is given by:
  - i.  $(\frac{2}{5}, \frac{2}{5}, \frac{1}{5})$
  - ii.  $(\frac{1}{5}, \frac{2}{5}, \frac{2}{5})$
  - iii.  $(\frac{1}{2}, \frac{1}{4}, \frac{1}{4})$
  - iv.  $(\frac{3}{5}, \frac{1}{5}, \frac{1}{5})$
  
- e. The interpolated color at P is given by:
  - i.  $\frac{1}{5}$
  - ii.  $\frac{1}{2}$
  - iii.  $\frac{1}{4}$
  - iv.  $\frac{3}{8}$
  
- f. The illumination at P using Phong Shading is:
  - i.  $\frac{15}{32}$
  - ii.  $\frac{1}{4}$
  - iii.  $\frac{9}{40}$
  - iv.  $\frac{1}{2}$



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**7) [4+3+4+3=14]** In the following image, the light source and the eye are denoted by L and E respectively. On surface AC the normals at A and C are  $N_A=(-1,1,0)$  and  $N_C=(1,1,0)$  respectively. Everything is drawn to scale. Use the illumination model given by  $I = I_a k_a + I_L k_d (\mathbf{N} \cdot \mathbf{L}) + I_L k_s (\mathbf{R} \cdot \mathbf{V})^n$ , where R denotes the reflected light vector at the surface point,  $I_a=0.8$ ,  $I_L=0.8$ ,  $k_a=0.2$ ,  $k_d=0.5$ ,  $k_s=0.5$ ,  $n=1$ .

*Hint: No need to normalize vectors. Treat negative dot products as 0.*



**a.** The diffuse illumination at B using Gouraud shading model is:

- i.** 0.0
- ii.** 0.6
- iii.** 0.8
- iv.** 3.2

**b.** The diffuse illumination at B using Phong shading model is:

- i.** 0.0
- ii.** 0.6
- iii.** 0.8
- iv.** 3.2

**c.** The specular illumination at B using Gouraud shading model is:

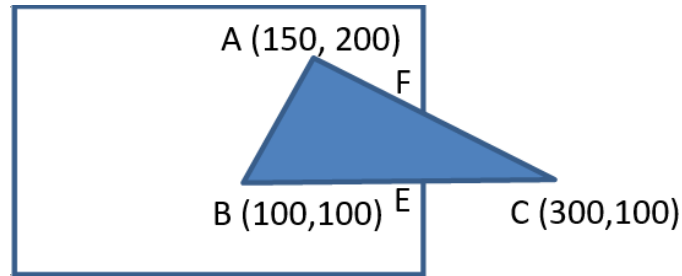
- i.** 0.0
- ii.** 1.08
- iii.** 1.44
- iv.** 3.2

**d.** The specular illumination at B using Phong shading model is:

- i.** 0.0
- ii.** 1.08
- iii.** 1.44
- iv.** 3.2

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**8) [2+1+2+3+4+3+1=16]** Consider the triangle ABC being clipped at E & F.



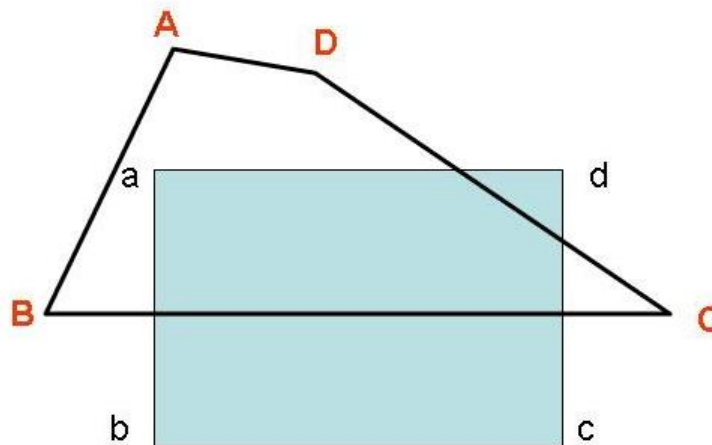
- a.** If F is the middle point of BC, its coordinate is:
- i.** 200,100
  - ii.** 225, 150
  - iii.** 225, 100
  - iv.** 200, 125
- b.** Therefore, the x-max for the window is:
- i.** 225
  - ii.** 200
  - iii.** 250
- c.** And the coordinates of E are:
- i.** 250,100
  - ii.** 225,100
  - iii.** 200,150
  - iv.** 150,150
- d.** The interpolation coefficients of B & C in order to compute E is:
- i.** 3/4
  - ii.** 3/8
  - iii.** 3/16
- e.** If the grayscale colors at B & C are 120 & 40 respectively, the interpolated grayscale value at E is:
- i.** 50
  - ii.** 70
  - iii.** 80
  - iv.** 100

**Question 8 continues to the next page**

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- f. If the Z-value at B and C are 24 & 40 respectively, the interpolated depth at E is:
- 32
  - 34
  - 36
  - 38
- g. When rendering E, you find that the depth buffer at that point is set at 40. Would E pass the depth buffer test?
- Yes
  - No

9) [2+1=3] The square **abcd** is the window in which a scene is to be rendered. The projection of a quadrilateral in the screen space is given by **ABCD**. Consider using Sutherland-Hodgeman's algorithm to clip this polygon. The order of the window edges to be considered is right, bottom, left and top.



- a. The clipping at the right edge of the window will result in the clipping of the which of the following edges:
- AD
  - CD
  - BC
  - AB
- b. The biggest contributor to the efficiency of Sutherland-Hodgeman's technique is:
- Integer Computation
  - Edge Table Data Structure
  - Pipelining
  - Spatial Subdivision

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**10) [1+2+2=5]** Consider an octree data structure for spatial subdivision being used for view frustum culling.

- a.** Each node of an octree has:
  - i.** 2 children
  - ii.** 4 children
  - iii.** 8 children
  - iv.** 16 children
  
- b.** If the bounding volume of the root of the octree is known, one can calculate the bounding volume of:
  - i.** Only the level 1 nodes
  - ii.** All the other nodes
  - iii.** Only the leaf nodes
  
- c.** View frustum culling is effectively finding:
  - i.** A cut of the octree
  - ii.** Height of the octree
  - iii.** Ordered traversal of the octree

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**11) [2+2+2+1+2+1+2+1+4=17]** Consider rasterizing the line AB where  $A=(4,8)$  &  $B=(7,10)$  and their respective gray colors are 0.2 & 0.8 respectively. The following questions are assume rasterizing this line using Bresenham's integer arithmetic method.

- a.  $dy$  is given by:
  - i. 1
  - ii. 2
  - iii. 3
  
- b.  $dx$  is given by:
  - i. 1
  - ii. 2
  - iii. 3
  
- c. The decision factor  $d$  is initialized to:
  - i. -1
  - ii. -2
  - iii. 1
  - iv. 2
  - v. 3
  
- d. The pixel chosen in the first step is:
  - i. E
  - ii. NE
  
- e. The updated  $d$  after this step is given by:
  - i. -1
  - ii. -2
  - iii. 1
  - iv. 2
  - v. 3
  
- f. The pixel chosen in the second step is:
  - i. E
  - ii. NE
  
- g. The updated  $d$  after this step is:
  - i. -1
  - ii. -2
  - iii. 1
  - iv. 2
  - v. 3

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- h.** The pixel chosen in the third step is:
  - i.** E
  - ii.** NE
  
- i.** The interpolated color of the pixel in the second step is given by:
  - i.** 0.2
  - ii.** 0.4
  - iii.** 0.6
  - iv.** 0.8