Student Number: **Name:**

Write down answers in-between questions. Please answer using short sentences.

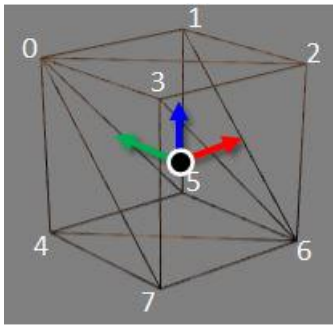
The back of each page can be used for practice, but DO NOT write down the answer on the back.

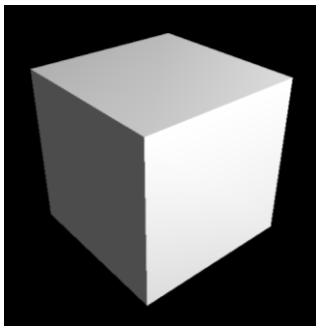
Be sure to write your student number and name on each page.

1. (5 pts) Choose ALL correct description for good settings for legacy OpenGL lighting, which is based on Phong illumination model.

   1) glLightfv(): Set the light source color to GL_DIFFUSE and GL_SPECULAR.
   2) glMaterialfv(): Set the material color to GL_DIFFUSE and GL_SPECULAR.
   3) Final color is the sum of ambient, diffuse, specular components.
   4) Each component of the final color is formed by adding the glMaterial color by the glLight color for each color channel.

2. (6 pts) Fill in the blanks (a) – (f) in the code below to render the cube model described by the image and table on the left like the image on the right.





vertex index	position
0	(-1 , 1 , 1)
1	(1 , 1 , 1)
2	(1 , -1 , 1)
3	(-1 , -1 , 1)
4	(-1 , 1 , -1)
5	(1 , 1 , -1)
6	(1 , -1 , -1)
7	(-1 , -1 , -1)

Student Number: **Name:**

```
def create():
    varr = np.array([
           (  (a)  ),
           ( -1 ,  1 ,  1 ),
           (  (b)  ),
           (  1 , -1 ,  1 ),
           (  (c)  ),
           (  1 ,  1 ,  1 ),
           ...
           (  (d)  ),
           ( -1 ,  1 ,  1 ),
           (  (e)  ),
           (  1 ,  1 ,  1 ),
           (  (f)  ),
           (  1 ,  1 , -1 ),
           ...
           ], 'float32')
    return varr

def drawCube():
    varr = create()
    glEnableClientState(GL_VERTEX_ARRAY)
    glEnableClientState(GL_NORMAL_ARRAY)
    glNormalPointer(GL_FLOAT, 6*varr.itemsize, varr)
    glVertexPointer(3,GL_FLOAT,6*varr.itemsize,
ctypes.c_void_p(varr.ctypes.data + 3*varr.itemsize))
    glDrawArrays(GL_TRIANGLES, 0, int(varr.size/6))
```

3. (5 pts) Let's say **p** is a homogeneous coordinates representation of the position of a vertex v on an object w.r.t. the object's local frame. Initially, the object's local frame coincides with the global frame.

   The object is transformed as follows w.r.t. the object's local frame:

   First, transformed by 4x4 matrix A,

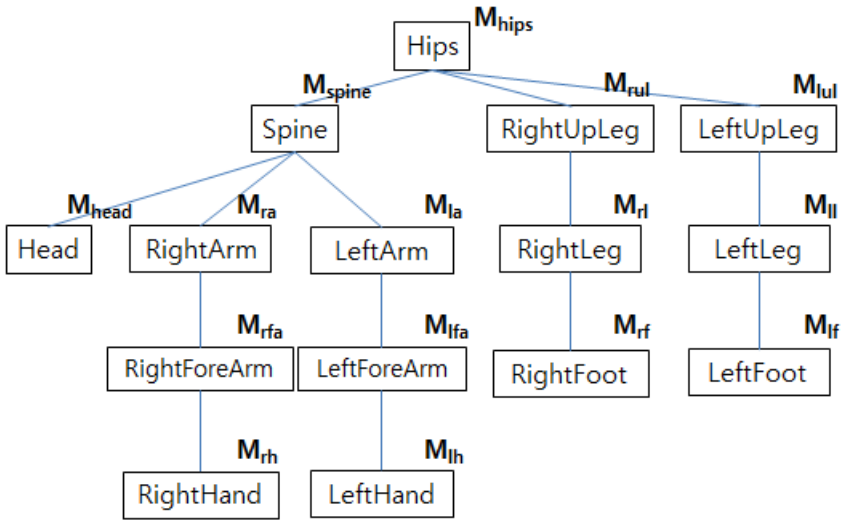
   Then, transformed by 4x4 matrix B,

   Finally, transformed by 4x4 matrix C,

   What is the position of the vertex v w.r.t. the global frame after these transformations?

4. (5 pts) Let's say each part of the following hierarchical model is rendered as a unit cube and **p** is a homogeneous coordinates representation of the position of a vertex v on the unit cube w.r.t. the cube's local frame. What is the global position of the vertex v of the unit cube rendering the "RightForeArm" part? Note that $\mathbf{M}_{xx}$ indicates the transformation of the corresponding part w.r.t. its parent part's frame (Assume that "Hips" part's parent frame is the global frame).

Student Number: **Name:**



5. (5 pts) $\mathbf{R_1}$ and $\mathbf{R_2}$ are rotation matrices. Write down a rotation matrix that rotate a frame defined by $\mathbf{R_1}$ to be coincident with the frame defined by $\mathbf{R_2}$ when applied w.r.t. the frame $\mathbf{R_1}$. Assume that a rotation matrix can represent an affine frame with a origin at the global origin.

6. (5 pts) Let's say that Rx(θ), Ry(θ), Rz(θ) represent rotation matrices about x, y, z axes, respectively, by θ rad. What is the rotation matrix for ZXY Euler angles with rotation angles of 0.2 rad about x axis, 0.5 rad about y axis, 1.0 rad about z axis? Use the symbols in the problem to write down the answer.

7. (5 pts) Choose **ALL** impossible combinations for Euler angles.

   1) XYZ
   2) ZXZ
   3) ZXX
   4) YZX
   5) YYX
   6) YXY

8. (10 pts) The following text is the hierarchy section of a bvh file which has 6 joints. If each joint's position w.r.t. global frame at T-pose (when all motion values are zeros) is given as the following

Student Number: **Name:**

table, fill in the blanks (a), (b), (c), (d), and (e).

joint	global position
J0	(0.0, 0.0, 0.0)
J1	(0.5, 0.5, 0.0)
J2	(0.75, 1.0, 0.0)
J3	(0.25, 1.0, 0.0)
J4	(-0.5, 0.5, 0.0)
J5	(-0.5, 1.0, 0.0)

```
HIERARCHY
ROOT J0
{
	OFFSET 0.00   0.00   0.00
	CHANNELS 6 Xposition Yposition Zposition Zrotation Xrotation
Yrotation
	JOINT J1
	{
		OFFSET  ____(a)____
		CHANNELS 3 Zrotation Xrotation Yrotation
		JOINT J2
		{
			OFFSET  ____(b)____
			CHANNELS 3 Zrotation Xrotation Yrotation
			End Site
			{
				OFFSET  0.00   0.50   0.00
			}
		}
		JOINT J3
		{
			OFFSET  ____(c)____
			CHANNELS 3 Zrotation Xrotation Yrotation
			End Site
			{
				OFFSET  0.00   0.50   0.00
			}
		}
	}
	JOINT J4
	{
		OFFSET  ____(d)____
		CHANNELS 3 Zrotation Xrotation Yrotation
		JOINT J5
		{
			OFFSET  ____(e)____
			CHANNELS 3 Zrotation Xrotation Yrotation
			End Site
			{
				OFFSET  0.00   0.50   0.00
			}
		}
	}
}
```

Student Number: **Name:**

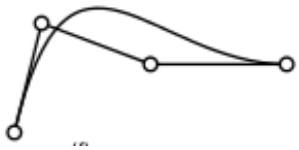
9. (8 pts) What is the position of "link2" joint w.r.t. global frame at the first frame? Use T(v) for translation (v is a vector), Rx(θ), Ry(θ), Rz(θ) for rotation (θ in degrees), and **O** for the homogeneous coordinate representation of the origin point.

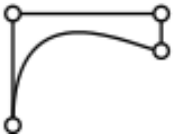
```
HIERARCHY
ROOT link0
{
  OFFSET  0  0  0
  CHANNELS 6 Xposition Yposition Zposition Xrotation Yrotation
Zrotation
  JOINT link1
  {
    OFFSET   1  0  0
    CHANNELS 3 Zrotation Xrotation Yrotation
    JOINT link2
    {
      OFFSET   0  1  0
      CHANNELS 3 Zrotation Xrotation Yrotation
      End Site
      {
        OFFSET   0  0  1
}}}}
MOTION
Frames:    1
Frame Time: 0.033333
3 2 1 30 20 10 40 50 60 0 0 0
```

10. (6 pts) Below are four curves and their "control points/polygon." Some of the control polygons are the Bezier control polygon for the curve drawn with it; the others are not. Choose **ALL non-Bezier curve & control polygon**. You may assume that none of the control points overlap or are repeated.

a. 

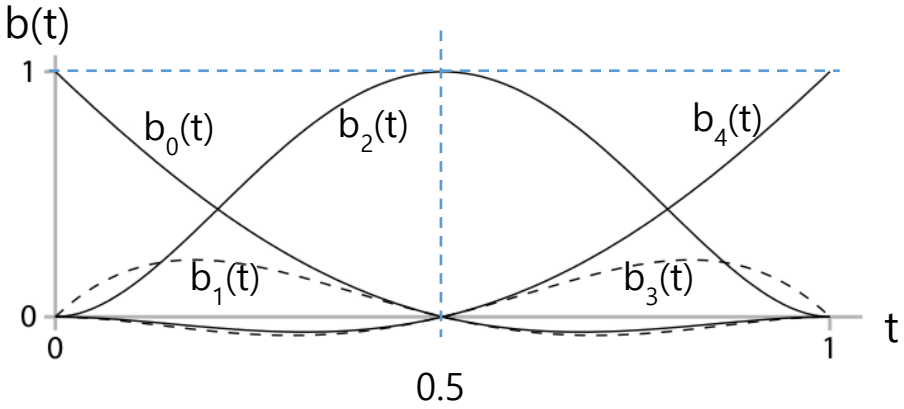
b. 

c. 

d. 

11. (10 pts) Let's say we have some "unfamiliar" quartic (fourth degree) polynomial curve, which has five basis functions $b_0(t)$, $b_1(t)$ $b_2(t)$, $b_3(t)$, $b_4(t)$ and corresponding control points $\mathbf{p_0}$, $\mathbf{p_1}$, $\mathbf{p_2}$, $\mathbf{p_3}$, $\mathbf{p_4}$. The following figure shows the basis functions (black solid and dashed curves are the basis functions):

Student Number: **Name:**

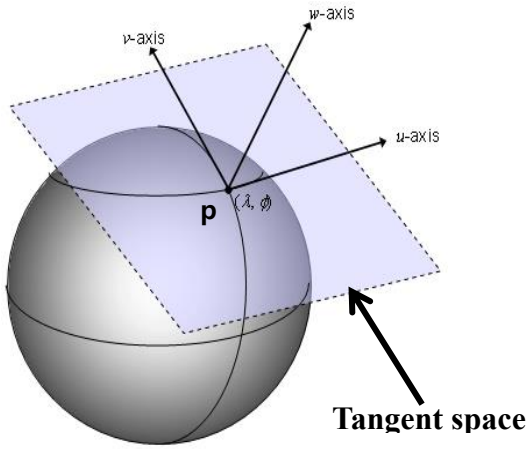


1) Write down the curve equations **p**(t) in parametric form, formulating with given basis functions and control points.

2) Which of the five control points $\mathbf{p}_0$, $\mathbf{p}_1$, $\mathbf{p}_2$, $\mathbf{p}_3$, $\mathbf{p}_4$ will the curve pass through, and for what values of t?

12. (6 pts) Write down the lowest-degree polynomial x(t) that passes through 3 data points x(0)=1, x(1)=-2, and x(2)=3.

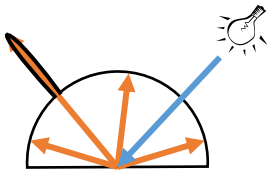
13. (6 pts) In the following figure, the surface normal vector at a point **p** on the sphere object is identical to the w-axis vector, which is perpendicular to the tangential plane at **p**. Let's say a tangent-space normal map to be applied to this sphere object encodes real normal vectors of this sphere's surface. Then, what are the RGB color values of the pixel in the normal map image, corresponding to the u, v coordinates of the point **p**? Note that the values of R, G, and B channels are expressed as integers from 0 to 255, and imply the u, v, and w axis components of the normal vector, respectively.



Student Number: **Name:**

14. (4 pts) Choose the BRDF for each of the objects 1), 2), 3), and 4) below.

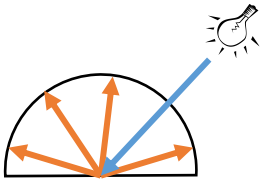
1) 

a. 

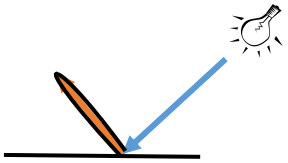
2) 

b. 

3) 

c. 

4) 

d. 

1):_____

2):_____

3):_____

4):_____

Student Number: **Name:**

15. (9 pts) Below is the pseudo code for z-buffer (depth buffer) algorithm. Fill in the blanks (a), (b), and (c). You have to use functions already used in the code and variables already defined in the code. Additionally, you can use a function call `read_depth_buffer(x,y)` to get the current recorded depth value at (x,y).

```
allocate depth_buffer;

for each pixel (x,y)
    write_frame_buffer(x,y,backgrnd_color);
    write_depth_buffer(x,y,farPlane_depth);

    for each polygon
        for each pixel (x,y) in polygon
            new_color = polygon's color at (x,y);
            new_depth = polygon's z-value at (x,y);
            if (___________(a)____________)
                ___________(b)____________;
                ___________(c)____________;
```

16. (5 pts) Choose **ALL** false(incorrect) statements about the visibility problem.

    3) Invisible primitives should be removed for efficient and correct rendering.

    4) Clipping is the process of removing primitives occluded by other objects closer to the camera.

    5) Back-face culling uses the dot product between surface normal and camera view vector.

    6) Painter's algorithm is the most popular hidden surface removal algorithm.