Name ______________________

GPU Programming
LSU EE 4702-1
Final Examination

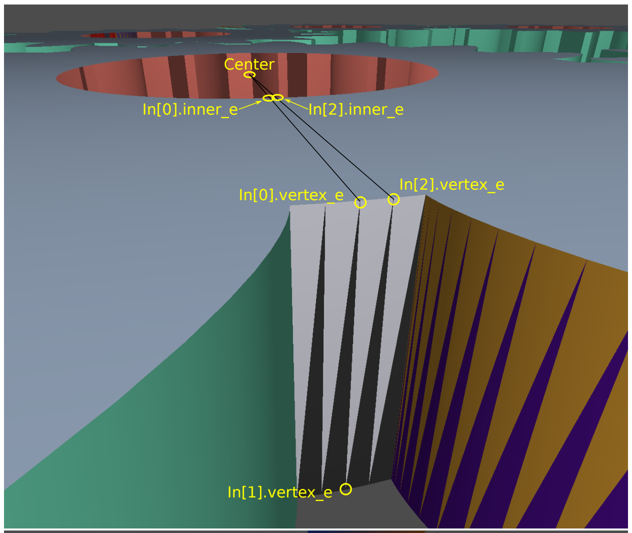
Wednesday, 7 December 2022 15:00-17:00 CST

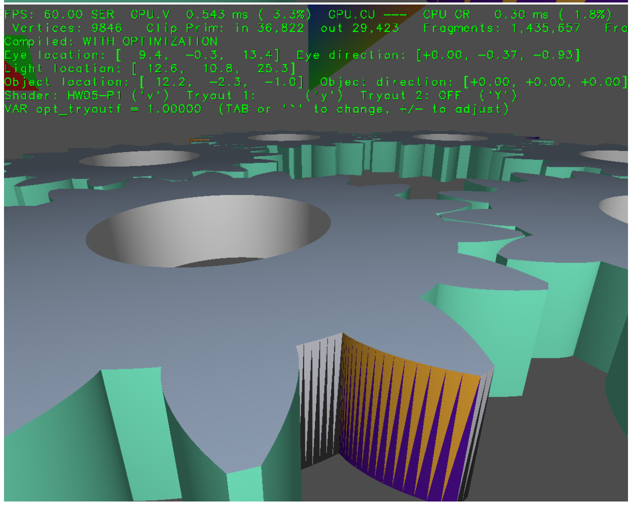
Problem 1	______	(20 pts)
Problem 2	______	(20 pts)
Problem 3	______	(15 pts)
Problem 4	______	(30 pts)
Problem 5	______	(15 pts)
Exam Total	______	(100 pts)

Alias ______________________

Good Luck!

Problem 1: [20 pts] Appearing below is the geometry shader based on Homework 5, Problem 1, in which gears were rendered.





```
FPS: 60.00 SER  GPU.V  0.543 ms ( 3.3%)  GPU.CU ---   CPU GR   0.30 ms ( 1.8%)
 Vertices: 9846   Clip Prim: in 36,822  out 29,423   Fragments: 1,435,657   Fra
Compiled: WITH OPTIMIZATION
Eye location: [  9.4,  -0.3,  13.4]  Eye direction: [+0.00, -0.37, -0.93]
Light location: [ 12.6,  10.8,  25.3]
Object location: [ 12.2,  -2.3,  -1.0]  Object direction: [+0.00, +0.00, +0.00]
Shader: HW05-P1 ('v')  Tryout 1:      ('y')  Tryout 2: OFF  ('Y')
VAR opt_tryoutf = 1.00000  (TAB or '`' to change, +/- to adjust)
```

(*a*) The screenshot to the upper right shows how coordinates provided to the geometry shader, such as `In[0].inner_e`, relate to the gear. In the screenshot to the lower right the gear hole has walls, shown in white. Add code to the shader so that the walls are rendered. (The code rendering the sides of the gear [shown in gray] is not shown, and should be ignored for this problem.) *Hint: Don't write too much code. A loop is needed, but a correct solution does not need code before the loop.*

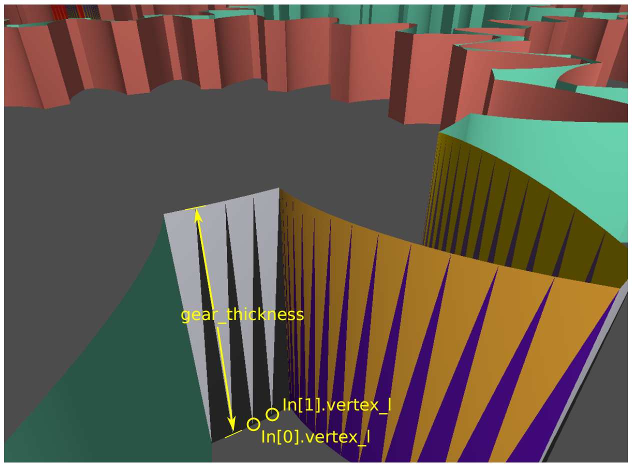
☐ Add code to render the walls.

☐ Be sure to correctly compute the normal, including for points on the lands (such as the purple/gold section).

☐ Use color index 7 for the walls.

☐ Make sure that the front of the triangle is visible.

```
layout ( triangles ) in;
layout ( triangle_strip, max_vertices=8 ) out;
layout (location = 0) in Data_VG {
  vec4 vertex_c, vertex_e, inner_c, inner_e;
  vec3 normal_e;
  int color_idx;
} In[];

void gs_main_prob1() {  /// Geometry Shader
  for ( int i=0; i<3; i++ ) {    // Emit edge of gear (lands and faces).
      gl_Position = In[i].vertex_c;
      vertex_e = In[i].vertex_e;
      normal_e = In[i].normal_e;
      color_idx = In[i].color_idx;
      EmitVertex();
    }
  EndPrimitive();

  // Add code for hole walls here.
```



(*b*) The geometry shader below correctly renders the gear (not the sides) and was written for a geometry shader input set to triangles (three vertices each). Modify the geometry shader so that it works when the geometry shader input is set to lines (two vertices each). The vertices provided are labeled in the screenshot to the right. These are vertices at $z = 0$ in local space. The (The output of the geometry shader remains a triangle strip.)

Input `vertex_l` is a local space coordinate along the bottom of the gear. The code correctly transforms these to eye and clip space. Modify the code so that it computes the coordinates along the top of the gear (`In[0]` and `In[2]` in the previous problem), and then emits triangles for the edge (but not the sides).

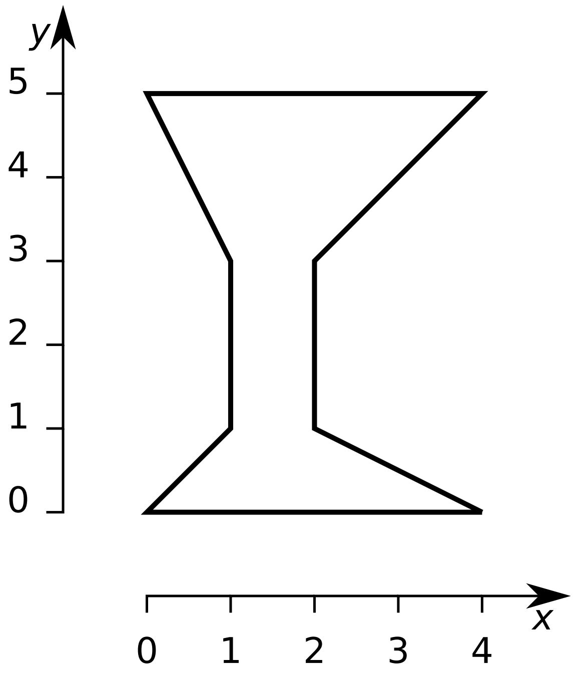
☐ Modify code so that it works for line strip input, and uses `gear_thickness` to compute the upper gear coordinates.

☐ Hint: Will need to update `max_vertices`. ☐ Hint: Not much more code is needed.

```
layout ( lines ) in; // Changed from triangles to lines.
layout ( triangle_strip, max_vertices = 3 ) out;  // [ ] Update as needed.
void gs_main_prob2() {   /// Geometry Shader
  int inst_idx = In[0].inst_idx;
  mat4 g_from_l = gears_xform[inst_idx] * rot;
  mat3 e_from_l = mat3(ut.eye_from_object) * mat3(g_from_l);
  vec4 avertex_e[3], vertex_c[3];
  vec3 anormal_e[3];
  float gt = gear_thickness; // Gear height in z axis in local space.

  for ( int i=0; i<3; i++ )
   {
      vec4 vertex_o = g_from_l * In[i].vertex_l;
      // Compute clip- and eye-space coordinates for vertex and normal.
      vertex_c[i] = ut.clip_from_object * vertex_o;
      avertex_e[i] = ut.eye_from_object * vertex_o;
      anormal_e[i] = normalize( e_from_l * In[i].normal_l );
    }



  for ( int i=0; i<3; i++ ) {
      gl_Position = vertex_c[i];
      vertex_e = avertex_e[i];
      normal_e = anormal_e[i];
      color_idx = In[i].color_idx;
      EmitVertex(); }
  EndPrimitive();
}
```

Problem 2: [20 pts] Answer the questions below about rendering an hourglass figure.

(*a*) Add coordinates to the buffer set below so that it renders the illustrated figure as a triangle strip. The z coordinate of all points is zero. Note that `pC(x,y)` can be used as an abbreviation for `pCoor(x,y,0)`. The first coordinate, `pC(0,0)`, is already inserted.



☐ Insert coordinates so that the buffer set renders the figure ☐ as a triangle strip.

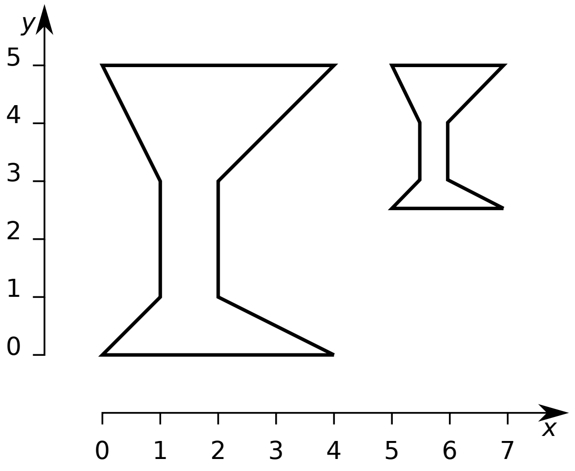
☐ Don't overlap triangles.

☐ Just insert coordinates, don't insert normal, colors, or anything else.

```
bset_hg.reset(pipe_hg);
auto pC = [&](float x, float y)
  { return pCoor(x,y,0); };
```

```
bset_hg << pC(0,0) <<
```

(*b*) The figure to the right shows the hourglass from the previous problem in its original position (which is described by `bset_hg`), and a second time in a new position (which is to be described by `bset_hg2`). Buffer set `bset_hg` contains the coordinates for the hourglass in its original position. The code below inserts coordinates into `bset_hg2` using coordinates from `bset_hg` transformed using `m`. Complete the code so that `m` is assigned an appropriate transformation matrix. For reference, several standard transformation matrices are provided below.



☐ Compute `m` to transform larger hourglass to smaller hourglass.

☐ Note that there is a change in position and in size. ☐ Pay attention to the order in which transformations are applied.

```
// The declarations below are for reference.
float angle, scale_factor;
pVect vec;
pMatrix_Rotation mat_r(axis,angle);
pMatrix_Translate mat_t(vec);
pMatrix_Scale mat_s(scale_factor);
// The declarations above are for reference.

// Note: bset_hg already has coordinates of hourglass.
```

```
pMatrix m = ;

for ( pCoor c: bset_hg.pos ) bset_hg2 << m * c;
```

Problem 3: [15 pts] Answer the following questions about clip and eye space.

(*a*) Draw a diagram illustrating the view volume. The diagram should include the eye, the near plane, and the far plane.

☐ Diagram showing eye, view volume, near plane, and far plane.

(*b*) Answer the following questions.

☐ The near plane distance was supposed to be set to 4.3. It is accidentally changed to 8.6. How does this affect the scene?

Note: The question in the original exam was: "What would happen if the near plane were too far from the eye?"

☐ What is the practical disadvantage of making the far plane too far from the eye?

(*c*) In a scene the user's eye is at location `eloc` (type `pCoor`) and the center of the user's monitor is at location `mloc` (type `pCoor`). The user is looking straight at the monitor, so it will appear as a rectangle, not as a trapezoid. The width of the user's monitor is `mwid` (type float). All of these dimensions are in global space. (For this problem consider object space equivalent to global space.)

Given this information plus needed assumptions compute the `eye_from_object` and `clip_from_eye` transformations. Some declarations have been provided for reference.

☐ Compute the `eye_from_object` transform. (OpenGL name: `gl_ModelViewMatrix`.)

☐ Compute the `clip_from_eye` transform. (OpenGL name: `gl_ProjectionMatrix`.)

☐ Make sure that `near` in the frustum transform is set correctly. ☐ Make sure that `height` in the frustum is set correctly, so that squares remain squares.

```
const int win_width = vh.s_extent.width;    // Frame buffer window width
const int win_height = vh.s_extent.height;
const float aspect = float(win_width) / win_height;

const float mwid = app.global_space_monitor_width;
const pCoor mloc = app.global_space_monitor_location;
const pCoor eloc = app.global_space_eye_location;

// Matrix examples below are for reference.
pMatrix_Rows m_r3( ax, ay, az );
// Rotate so that m_r3 * ax -> pVect(1,0,0), m_r3 * az -> pVect(0,0,1),...

pMatrix_Rotation m_r1( vec1, vec2 );
// Rotate so that m_r1 * vec1 = vec2;

pMatrix_Translate m_tlate(vec);
// Translate so that m_tlate * P -> P + vec;

pMatrix_Frustum m_frust( width, height, near, far );
// Width and height of "monitor" (small part of frustum).
// Near plane distance, far plane distance.

// Matrix examples above are for reference.
```

```
pMatrix eye_from_object = ;

pMatrix clip_from_eye = ;
```

Problem 4: [30 pts] Answer the following questions about rendering pipelines and shaders.

(a) Answer the following questions about shaders used for rasterization under Vulkan (or OpenGL).

☐ To render just one triangle in the whole scene, how many times would a vertex shader *typically* be called?

☐ Describe how it is possible to render T triangles with $T + 2$ invocations of a vertex shader.

☐ Describe how it is possible to render T triangles with T invocations of a vertex shader.

☐ To render one triangle in the whole scene, how many times would a geometry shader typically be invoked?

☐ A geometry shader is invoked G times. Why is it not possible to determine how many triangles are rendered?

☐ What does one need to know about a triangle to determine how many times a fragment shader is invoked to render the triangle?

(*b*) Answer the following questions about shaders in a Vulkan (NVidia or Khronos extension) ray tracing "pipeline".

☐ What does one need to know to determine how many times is the ray generation shader invoked? ☐ Provide an example.

☐ The ray generation shader casts a ray. In what direction does it cast the ray?

☐ The ray generation shader used in class set its ray payload, a four-element vector, to zero. What does it do with the payload after the ray is cast?

(*c*) Consider a scene that can be rendered using ray tracing or using rasterization. This was the case for many classroom examples. Consider a scene without shadows and without reflections.

☐ For the same scene, which is invoked more often, the fragment shader or the nearest hit shader? ☐ Explain.

Problem 5: [15 pts] Answer each question below.

(*a*) Consider Vulkan buffers bound to a pipeline as uniform buffers or as storage buffers.

☐ Both a uniform buffer and a storage buffer can hold arrays. ☐ Which is better for larger arrays?

☐ Both uniform buffers and storage buffers can be used to store a single (meaning just one) object, such as a transformation matrix or small structure. ☐ Which is better for single objects, and why?

(*b*) Textures are read using a built-in function in the fragment shader, such as `vec4 texel = texture(tex_unit_0,tex_coor);`.

☐ What are the range of values for `tex_coor`? How does that relate to the texture?

☐ How does the `texture` builtin function determine which MIPMAP level to use when retrieving texels?