Name _____

GPU Programming
EE 4702-1
Final Examination

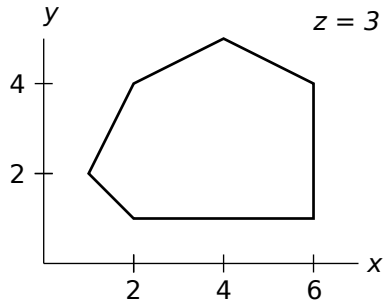
Tuesday, 4 December 2018 12:30–14:30 CST

Problem 1	_____	(15 pts)
Problem 2	_____	(30 pts)
Problem 3	_____	(15 pts)
Problem 4	_____	(40 pts)
Exam Total	_____	(100 pts)

Alias _____

Good Luck!

Problem 1: [15 pts] Appearing below is a geometric figure.



(*a*) Complete the individual-triangle rendering pass below so that it renders the figure with all triangles facing in the positive z direction and without overlapping triangles. Use the provided abbreviation `glV`. *Note: The part about facing the $+z$ direction was not in the original exam.*

☐ Complete code to render shape using individual triangles.

```
#define glV glVertex3f
 glBegin(GL_TRIANGLES);




 glEnd();
```

(*b*) Complete the triangle-strip rendering pass below so that it renders the figure.

☐ Complete code to render shape using a triangle strip.

```
#define glV glVertex3f
 glBegin(GL_TRIANGLE_STRIP);




 glEnd();
```

Problem 2: [30 pts] Appearing below is shortened host and shader code based on Homework 3, in which text was drawn on the triangular spiral. One drawback of this code is that it uses old-fashioned, deprecated, inefficient `glVertex` calls. On the following pages are routines that will implement a more efficient version of this code in which data such as `ctr` are placed in buffer objects and a rendering pass is performed *for the entire chain*, not just one triangular spiral.

```
for ( int i=2; i<chain_length; i++ ) {  // Host Code
    pCoor p0 = balls[i-2].position, p1 = balls[i-1].position, p2 = balls[i].position;
    pCoor ctr = (p0+p1+p2)/3; // Compute location of triangle center.
    // --- CODE REMOVED FOR BREVITY ---
    pCoor pprev = ctr;
    float delta_a = 0.6 / opt_n_segs;

    if ( opt_shader == SO_HW03 ) {
        glBegin(GL_TRIANGLE_STRIP);  // Render spiral using 1 triangle strip.

        for ( int j=0; j<opt_n_segs; j++ ) {
            pVect v = va[j%3];                // Vector from center to fold.
            pCoor p = ctr + j * delta_a * v;  // Coordinate of fold.
            pNorm n = cross( p - pprev, vz ); // Normal of segment.
            float tex_x = total_len_compute(j,delta_a,distv) * tex_scale;

            glNormal3fv(n);
            glTexCoord2f(tex_x,0);  glVertex3fv(p + vz);
            glTexCoord2f(tex_x,1);  glVertex3fv(p - vz);
            pprev = p;
          }
        glEnd();
      } }
```

```
void vs_main_hw03() { // Vertex Shader Code
  gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
  vertex_e = gl_ModelViewMatrix * gl_Vertex;
  normal_e = normalize(gl_NormalMatrix  * gl_Normal);
  tex_coord = gl_MultiTexCoord0.xy;   }
```

(*a*) But first let c denote the value of `chain_length` and n denote the value of `opt_n_segs`. Determine the amount of data, in bytes, sent from the CPU to the GPU for the code shown above. (Do not consider uniforms and other hidden code.)

☐ Amount of data sent from CPU to GPU in terms of c and n, in bytes.

(*b*) In the vertex shader above, label variables with the appropriate letter as requested below.

☐ Label uniform variables with a **U**, ☐ shader input variables with an **I**, and ☐ fixed-function shader outputs with an **O**.

Problem 2, continued: Appearing below is the improved triangular spiral host code and shaders. The host code prepares four buffer objects and then starts an instanced rendering pass with line strips as the input primitive. The rendering pass uses a vertex shader and a geometry shader to complete the primitives. (The fragment shader is not a part of this problem.) The only inputs to the vertex shader are the vertex and instance IDs, which should be used to retrieve or compute information about the spiral segments.

```
// Host Code -- DO NOT MAKE OR ASSUME MODIFICATIONS TO THIS CODE.
      for ( int i=2; i<chain_length; i++ ) {
          // Put ball structures and coordinates into convenient variables.
          pCoor p0 = balls[i-2].position, p1 = balls[i-1].position, p2 = balls[i].position;
          pCoor ctr = (p0+p1+p2)/3;   ctr_a.push_back(ctr);

          // -- CODE PREPARING va_a, vz_a, and distv_a NOT SHOWN --
        }
      glUniform1i(5, opt_n_segs);
      TO_BUFFER_OBJECT(ctr_a,1);       TO_BUFFER_OBJECT(va_a,2);
      TO_BUFFER_OBJECT(distv_a,3);     TO_BUFFER_OBJECT(vz_a,4);
      glBindBuffer(GL_ARRAY_BUFFER,0);

      glDrawArraysInstanced(GL_LINE_STRIP, 0, opt_n_segs, ctr_a.size() );
```

(*c*) Modify the vertex and geometry shaders on the following pages to efficiently render the triangle spirals, make any needed changes to the interface blocks, but **do not modify** or assume modifications to the host code (above). For your convenience each shader contains a copy of the host code. Cross out or modify that code as needed. Use the handy abbreviations at the top of the page.

☐ Update the interface blocks as needed.

```
#ifdef _VERTEX_SHADER_
out Data {  // Out of Vertex Shader to Geometry Shader
 int ins_id, vtx_id;
 //  ☐   Add any needed declarations here.




};
#endif
#ifdef _GEOMETRY_SHADER_
in Data {  // In to Geometry Shader from Vertex Shader
 int ins_id, vtx_id;
 //  ☐   Add any needed declarations here.




} In[2];

// Out of Geometry Shader to Fragment Shader -- No changes needed
out Data {   vec3 normal_e;   vec4 vertex_e;   vec2 tex_coord;  };
#endif
```

Problem 2, continued: Vertex shader code on this page.

☐ Cross out unneeded code. ☐ Cross out data type for shader outputs. ☐ Avoid redundant computation.

☐ Update the interface blocks as needed.

```
const mat4 mv = gl_ModelViewMatrix, mvp = gl_ModelViewProjectionMatrix;
const mat3 nm = gl_NormalMatrix;

void vs_main_lines() {  // Vertex Shader Main Routine
  int ins_id = gl_InstanceID, vtx_id = gl_VertexID;

  int j = gl_VertexID;
  float delta_a = 0.6 / opt_n_segs;
  vec4 distv = distv_a[ins_id];
  vec3 vz = vz_a[ins_id].xyz;
  float tex_scale = 0.2;









  vec3 v = va_a[ins_id][j%3].xyz;
  vec3 p = ctr_a[ins_id].xyz + j * delta_a * v;
  vec3 pprev = vec3(0,0,0); // PLACEHOLDER. Won't work.
  vec3 n = cross( p - pprev, vz );
  float tex_x = total_len_compute(j,delta_a,distv) * tex_scale;









}
```

Problem 2, continued: Geometry shader code on this page.

☐ Cross out unneeded code. ☐ Cross out data type for shader outputs. ☐ Avoid redundant computation.

☐ Update the interface blocks as needed.

```
layout ( lines ) in;
layout ( triangle_strip, max_vertices = 4 ) out;

const mat4 mv = gl_ModelViewMatrix, mvp = gl_ModelViewProjectionMatrix;
const mat3 nm = gl_NormalMatrix;

void gs_main_lines() {  // Geometry Shader Main Routine
  int ins_id = gl_InstanceID, vtx_id = gl_VertexID; // PLACEHOLDER. Won't work.

  int j = 0;  // PLACEHOLDER, Won't work.
  float delta_a = 0.6 / opt_n_segs;
  vec4 distv = distv_a[ins_id];
  vec3 vz = vz_a[ins_id].xyz;
  float tex_scale = 0.2;









  vec3 v = va_a[ins_id][j%3].xyz;
  vec3 p = ctr_a[ins_id].xyz + j * delta_a * v;
  vec3 pprev = vec3(0,0,0); // PLACEHOLDER. Won't work.
  vec3 n = cross( p - pprev, vz );
  float tex_x = total_len_compute(j,delta_a,distv) * tex_scale;









}
```

Problem 3: [15 pts] Answer each CUDA question below.

(*a*) Both CUDA kernels below do the same thing, but one will execute much less efficiently. Explain why in terms of the minimum request size.

```
__global__ void kmain_simple(float4 *d_in, float *d_out) {
  const int tid = threadIdx.x + blockIdx.x * blockDim.x;
  const int elt_per_thread = ( d_app.array_size + d_app.num_threads - 1 ) / d_app.num_threads;
  const int start = elt_per_thread * tid;
  const int stop = start + elt_per_thread;

  for ( int h=start; h<stop; h++ ) {
      float4 p = d_in[h];
      float sos = p.x * p.x + p.y * p.y + p.z * p.z + p.w * p.w;
      d_out[h] = sos;
    }
}

__global__ void kmain_efficient(float4 *d_in, float *d_out) {
  const int tid = threadIdx.x + blockIdx.x * blockDim.x;
  for ( int h=tid; h<d_app.array_size; h += d_app.num_threads ) {
      float4 p = d_in[h];
      float sos = p.x * p.x + p.y * p.y + p.z * p.z + p.w * p.w;
      d_out[h] = sos;
    }
}
```

☐ Problem with inefficient kernel due to request size.

☐ What is the maximum request size that will avoid this inefficiency? ☐ Explain.

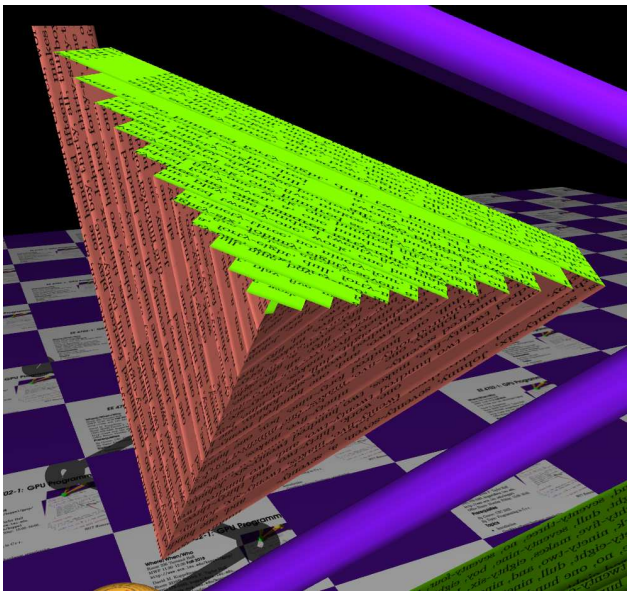
(*b*) A CUDA kernel is to run on a GPU with 8 SMs (MPs). Configuration A consists of 4 blocks of 32 threads each. Configuration B consists of 8 blocks of 16 threads each. Neither is very good. Explain how each one underutilizes the hardware on current NVIDIA GPUs.

☐ Configuration A underutilizes hardware by . . .

☐ Configuration B underutilizes hardware by . . .

Problem 4: [40 pts] Answer each question below.

(*a*) The screenshot below is the Homework 3 triangular spiral with 37 segments per spiral. Imagine a spiral with even more segments, say 1000.



With a large number of segments there will usually be a large computational load on both the vertex and fragment shaders. In one of these shaders the computational load can be considered wasted, depending on the eye location, **even when the spiral is visible**. In which shader is computation wasted, and why.

☐ Which shader wastes computation? ☐ Why?

Sketch two views in which the spiral is visible. In one the computational load is high and mostly wasted. In the other the computational load is lower and not wasted.

☐ View with lower load and little waste. ☐ View with high load and waste.

(*b*) The OpenGL call `glColor` is used to specify a color, say purple `glColor3f(1,0,1);`. In typical use is that the color that will be written to the frame buffer? Explain.

☐ Are the arguments to `glColor` the exact color to be written to the frame buffer? ☐ Explain.

(*c*) Describe the difference between the `flat`, `noperspective`, and `smooth` interpolation qualifiers.

☐ The `flat` qualifier's feature, ☐ the `noperspective` qualifier's, feature, ☐ the `smooth` qualifier's, feature.

(*d*) Consider a rendering pass using triangles as the primitive. OpenGL (compatibily profile) allows one to specify a normal for each triangle vertex, but as we all know a triangle, geometrically, has just one normal. Why would one specify different normals for each vertex? Explain how such normals are chosen.

☐ Why might one choose different normals for each vertex of a triangle?

☐ Give an example and describe how those normals are chosen.

(*e*) Describe what the inputs to the rasterization stage are, what the rasterization stage does, and what its outputs are.

☐ Rasterization stage input, ☐ rasterization stage job, ☐ rasterization stage output:

(*f*) The true-sphere shader used in class rendered spheres perfectly. Would it make sense to use a similar approach to write a true-cube shader that can perfectly render a cube?

☐ Does a true cube shader make sense? ☐ Explain.

(*g*) The unlabeled diagram below shows how shadow volumes can be used to render shadows. On the diagram show the location of the eye and light source, fragment(s) found to be in the shade, and fragment(s) found to be illuminated.

☐ Show: ☐ eye, ☐ light source, ☐ shaded fragment(s), ☐ illuminated fragment(s).