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GPU Programming
LSU EE 4702-1
Final Examination

Thursday, 7 December 2023 7:30-9:30 CST

Problem 1	_____	(20 pts)
Problem 2	_____	(20 pts)
Problem 3	_____	(10 pts)
Problem 4	_____	(15 pts)
Problem 5	_____	(20 pts)
Problem 6	_____	(15 pts)
Exam Total	_____	(100 pts)

Alias _____

Good Luck!

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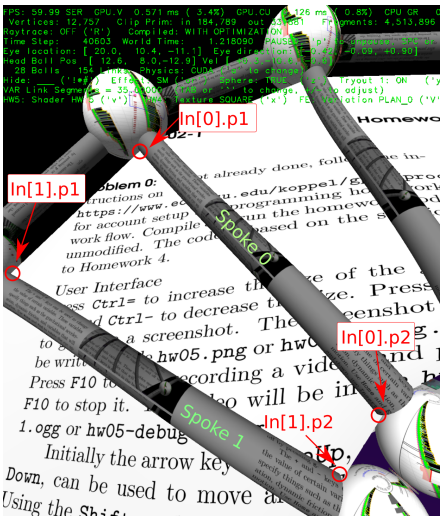
Problem 1: [20 pts] The geometry shader code below is from the solution to Homework 5. Each invocation draws the area between two spokes. The screen shot shows how some inputs to the geometry shader relate to the rendered image.

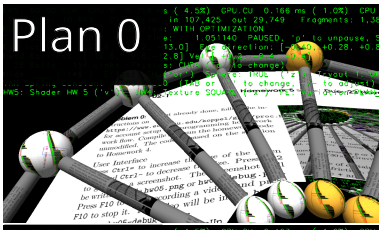


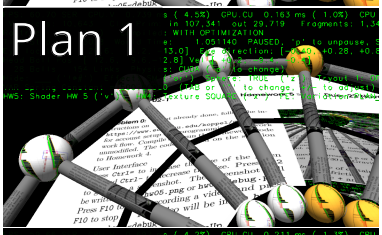
(*a*) In the original code `EndPrimitive()` was not called until after after the `s` loop. The code below calls `EndPrimitive()` inside the loop once when `variation=Plan_1` and at each iteration when `variation=Plan_s`. For `variation=Plan_0` the code is equivalent to the homework solution and it is the version used for the screenshot.

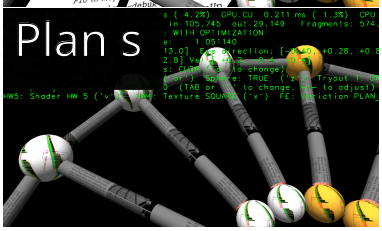
☐ Describe the appearance for `Plan_1`, draw a sketch. ☐ Explain.

☐ Describe the appearance for `Plan_s`, draw a sketch. ☐ Explain.

```
void gs_fe_ep() {
  for ( int s=0; s<=opt_segments; s++ ) {
    float t = float(s) / opt_segments;

    // Compute interpolated coords along spokes 0 and 1 using t.
    vec4 pos0t = bez( In[0].p1, In[0].p2, In[0].v1, In[0].v2, t );
    vec4 pos1t = bez( In[1].p1, In[1].p2, In[1].v1, In[1].v2, t );

    // Emit the vertex along spoke 0  ( In[0] )
    gl_Position = ut.clip_from_object * pos0t;
    Out.vertex_e = ut.eye_from_object * pos0t;
    Out.tex_coor = mix( In[0].tc1, In[0].tc2, t );
    EmitVertex();

    // Emit the vertex along spoke 1  ( In[1] ).
    gl_Position = ut.clip_from_object * pos1t;
    Out.vertex_e = ut.eye_from_object * pos1t;
    Out.tex_coor = mix( In[1].tc1, In[1].tc2, t );
    EmitVertex();

    switch ( variation ) {
    case Plan_0: break;  // Original. Same as Homework 5 solution.
    case Plan_1: if ( s == opt_segments/2 ) EndPrimitive(); break;
    case Plan_s: EndPrimitive(); break; }
  }
  EndPrimitive();
}
```







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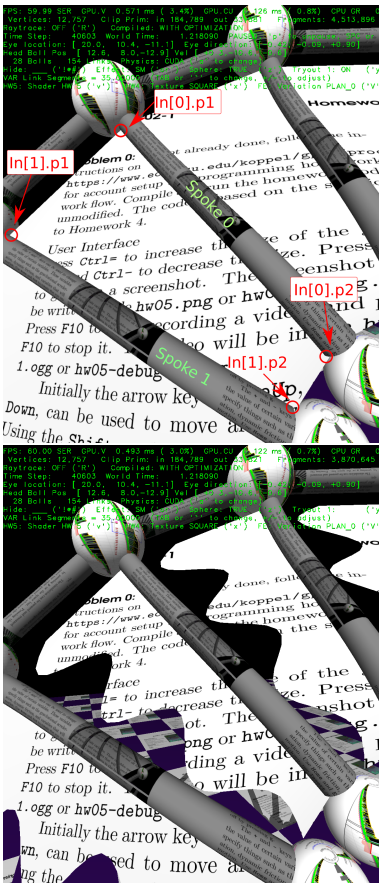
(*b*) The screenshot to the upper right is from the Homework 5 solution. The screenshot below shows the surface between the spokes with a sine-wavy cut. Modify the geometry shader to make that cut. Variable `width` shows how far the surface should extend. A value of 0.5 means the surface should reach halfway from one spoke to another, a value of 0.7 means the surface goes 70% of the way, etc.



☐ Modify the shader so that the surface extends `width` from Spoke 0 (thus forming the sine wavy shape) ☐ taking care that the texture appears as shown.

☐ Don't overdo it. Only a few lines are needed. The `mix` function might come in handy.

```
void gs_fe_sine() {
  for ( int s=0; s<=opt_segments; s++ ) {
      float t = float(s) / opt_segments; // delta_t
      float width = 0.5 + ampl * ( 1 + sin( t * omega ) );

      // Interpolate coordinate along each spoke.
      vec4 pos0t=bez( In[0].p1, In[0].p2, In[0].v1, In[0].v2, t);
      vec4 pos1t=bez( In[1].p1, In[1].p2, In[1].v1, In[1].v2, t);









      //  Emit the vertex along spoke 0  ( In[0] )
      gl_Position = ut.clip_from_object * pos0t;

      Out.vertex_e = ut.eye_from_object * pos0t;

      Out.tex_coor = mix( In[0].tc1, In[0].tc2, t );









      EmitVertex();

      // Emit the vertex along spoke 1  ( In[1] ).
      gl_Position = ut.clip_from_object * pos1t;

      Out.vertex_e = ut.eye_from_object * pos1t;

      Out.tex_coor = mix( In[1].tc1, In[1].tc2, t );









      EmitVertex();
    }
  EndPrimitive();
}
```

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Problem 2: [20 pts] The facing page shows CPU code that prepares the buffer set to draw the area between the spokes from the Homework 4 and Homework 5 solutions. The Homework 4 geometry shader is shown, the Homework 5 geometry shader code can be found in the previous problem. Texture coordinates have been omitted for simplicity.

The questions below are about the number of shader invocations and the amount of data per frame for the these code fragments. In your answers use n_s for the value of `n_spokes` and n_g for the value of `opt_segments`. The amount of data should be given in bytes. An integer and float are each 4 bytes.

☐ Per frame and in terms of n_s and n_g how many times is the vertex shader invoked for the ☐ Homework 4 version and the ☐ Homework 5 of the code?

☐ Per frame and in terms of n_s and n_g how many times is the geometry shader invoked for the ☐ Homework 4 version and the ☐ Homework 5 of the code?

☐ Per frame and in terms of n_s and n_g how many primitives are sent to the rasterizer for the ☐ Homework 4 version and the ☐ Homework 5 of the code?

☐ Per frame, does the Homework 4 code make ◯ *fewer fragment shader invocations*, ◯ *about the same number of fragment shader invocations*, or ◯ *more fragment shader invocations* than the Homework 5 code? ☐ Explain.

☐ Per frame and in terms of n_s and n_g how much data is sent from the CPU to the GPU for ☐ the Homework 4 version and ☐ the Homework 5 of the code? ☐ Account for data in the buffer sets and in storage buffers `pos1`, `v1`, etc.

```
/// Homework 4 CPU Code: Input topology is a triangle strip. Vertex attribute: pCoor
for ( size_t i = 0; i < n_spokes; i++ ) {
    size_t i2 = (i+1) % n_spokes;
    int link_idx_1 = hw04_stuff.ribs[i]->idx,  int link_idx_2 = hw04_stuff.ribs[i2]->idx;
    pCoor pos11 = lis_pos1[link_idx_1], pos12 = lis_pos2[link_idx_1];
    pVect v11 = lis_v1[link_idx_1], v12 = lis_v2[link_idx_1];
    pCoor pos21 = lis_pos1[link_idx_2], pos22 = lis_pos2[link_idx_2];
    pVect v21 = lis_v1[link_idx_2], v22 = lis_v2[link_idx_2];

    for ( int s=0; s<=opt_segments; s++ ) {
        const float t = float(s) / opt_segments;
        pCoor pos1t = bez(pos11,pos12,v11,v12,t),  pos2t = bez(pos21,pos22,v21,v22,t);
        if ( s == 0 ) bset_hw04_p2 << pos1t;
        bset_hw04_p2 << pos1t << pos2t;
        if ( s == opt_segments ) bset_hw04_p2 << pos2t;
      }
  }
bset_hw04_p2.to_dev();   pipe_hw04_p2.record_draw( cb, bset_hw04_p2 );

/// Homework 4 Vertex Shader
void vs_main() { Out.vertex_o = in_vertex_o; }

/// Homework 4 Geometry Shader
void gs_main() {
vec3 normal_o = cross( In[1].vertex_o.xyz - In[0].vertex_o.xyz,
                       In[2].vertex_o.xyz - In[0].vertex_o.xyz );
vec3 normal_e = mat3( ut.eye_from_object ) * normal_o;
for ( int i=0; i<3; i++ ) {
    gl_Position = ut.clip_from_object * In[i].vertex_o;
    Out.normal_e = normal_e;
    Out.vertex_e = ut.eye_from_object * In[i].vertex_o;
    EmitVertex();
  }
EndPrimitive();
}


/// Homework 5 CPU Code: Input topology is a line strip. Vertex attribute: integer (link_idx)
for ( size_t i = 0; i <= n_spokes; i++ )
    bset_hw05 << hw05_stuff.spokes[i%n_spokes]->idx; // Insert link index.
bset_hw05.to_dev();  pipe_hw05.record_draw( cb, bset_hw05 );

/// Homework 5 Vertex Shader
void vs_hw05() {
  Out.p1 = pos1[in_link_idx];   Out.p2 = pos2[in_link_idx]; // Get coords from storage buffer.
  Out.v1 = v1[in_link_idx];     Out.v2 = v2[in_link_idx]; }

// See prior problem for geometry shader.
```


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Problem 3: [10 pts] Appearing below are hourglass shapes with vertices numbered. The code below inserts vertex coordinates into a buffer set as part of **an unsuccessful attempt** to render that shape. The inserted *coordinates* are correct (and the vertex numbers shown in the comments match the diagram). The problem is their order and the number of times each vertex is inserted. (Vertex 4 is inserted twice, but that's not the only problem.)

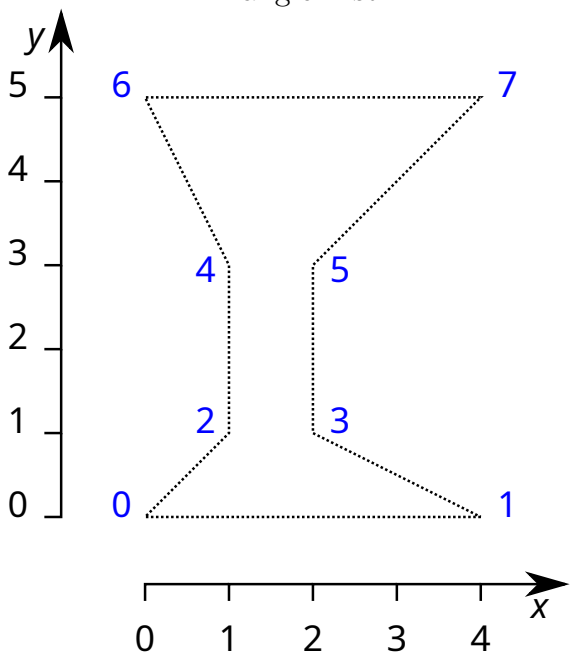
```
bset_hg
<< pCoor(0,0)  // Vtx 0
<< pCoor(4,0)  // Vtx 1
<< pCoor(1,1)  // Vtx 2

<< pCoor(1,3)  // Vtx 4
<< pCoor(2,1)  // Vtx 3
<< pCoor(2,3)  // Vtx 5

<< pCoor(4,5)  // Vtx 7
<< pCoor(0,5)  // Vtx 6
<< pCoor(1,3); // Vtx 4
```

Do not try to fix the code. Instead show the result of rendering with these coordinates for the topologies requested below.

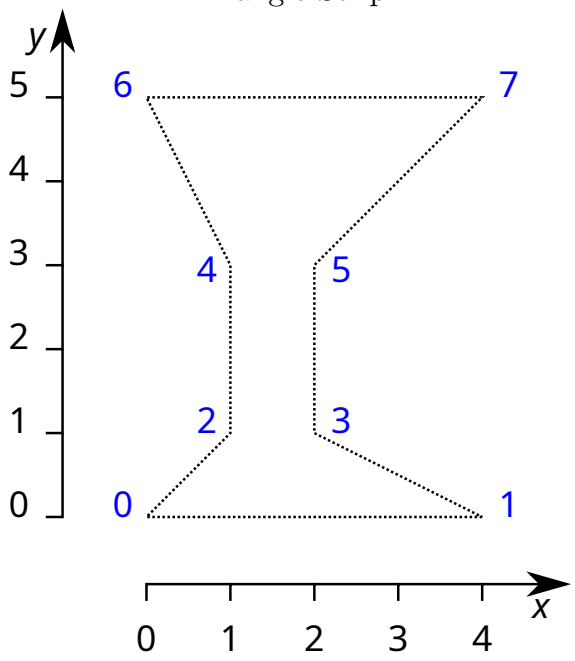
☐ On the diagram on the left sketch the triangles that will be rendered by the code below when the pipeline is set up for a triangle list.

☐ On the diagram on the right sketch the triangles that will be rendered by the code below when the pipeline is set up for a triangle strip.

Triangle List



Triangle Strip



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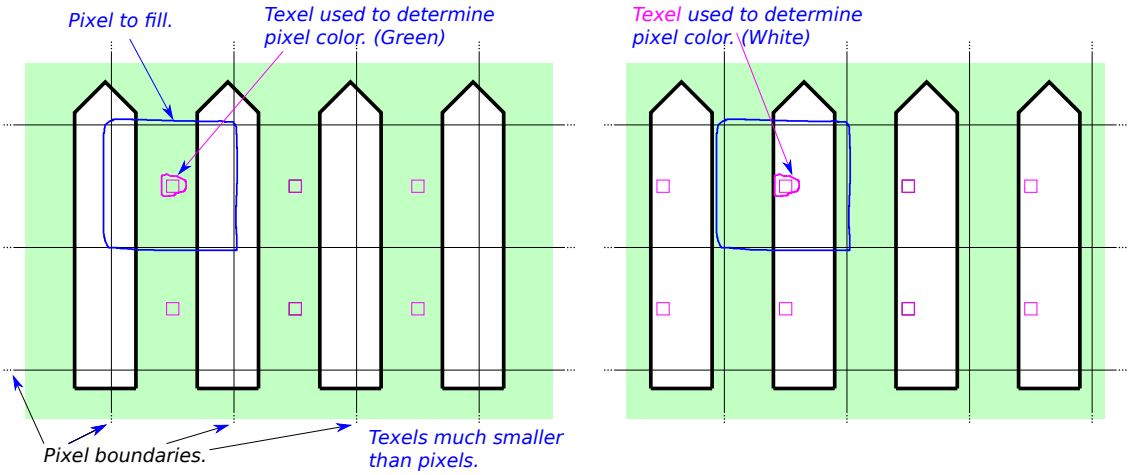
Problem 4: [15 pts] Answer the following texture questions.

(*a*) A texture at MIPMAP level 4 is 8192 bytes. What is the size of the image at MIPMAP level 5?

☐ The size of the image at level 5 is:

(*b*) The images below illustrate a problem that can occur when a texel size is much smaller than a pixel size. The texture image shows a white picket fence with green behind the fence (probably grass).



Suppose the eye in the scene illustrated above is slowly moving from left to right. What would be the major problem with the appearance of the scene?

☐ Major problem with appearance:

The solution to the problem is to use the average color of all the texels covering each pixel.

☐ When and where are texels averaged together? ☐ Why doesn't this averaging have an impact on rendering speed?

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Problem 5: [20 pts] Answer the following questions about low-level rendering code.

(*a*) The loop nest below iterates over the barycentric coordinates of a triangle to find fragments to write into the frame buffer. Variables `w0`, `w1`, and `w2` hold the window-space coordinates of the triangle vertices. Consider increments `db0` and `db1`.

```
for ( float b0=0; b0<=1; b0 += db0 )
  for ( float b1=0; b1<=1-b0; b1 += db1 ) {
      const float b2 = 1 - b0 - b1;
      pCoor wf = b0*w0 + b1*w1 + b2*w2;  // Window-space coordinate of fragment.
      frame_buffer[ wf.x + int(wf.y) * win_width ] = color;  }
```

☐ Describe the consequences if `db0` and `db1` are too small. Consider both ☐ correctness ☐ and performance.

☐ Describe the consequences if `db0` and `db1` are too large. Consider both ☐ correctness ☐ and performance.

(*b*) The rasterization code below uses either eye-space (perspective correct) barycentric coordinates `bc0`, `bc1`, and `bc2` or window-space barycentric coordinates to interpolate texture coordinates `tc0`, `tc1`, and `tc2`. Suppose a scene consists of two triangles forming a rectangle, and a texture is applied to the rectangle. The texture image shows a ruler (for measuring lengths).

```
for ( float b0=0; b0<=1; b0 += db0 )
  for ( float b1=0; b1<=1-b0; b1 += db1 ) {
     const float b2 = 1 - b0 - b1;
     pCoor wf = b0*w0 + b1*w1 + b2*w2;  // Window-space coordinate of fragment.

     float bc0 = 1/(f.w0ow2z*(1-b0)/b0+1),   bc1 = 1/(f.w1ow2z*(1-b1)/b1+1),  bc2 = 1-bc0-bc1;

     if ( use_eye ) tc = bc0*tc0 + bc1*tc1 + bc2*tc2; // Eye-space interpolation.
     else           tc = b0*tc0 + b1*tc1 + b2*tc2;    // Window-space interpolation.
     texel = texture2D(tc); // Look up and filter texel.

     frame_buffer[ wf.x + int(wf.y) * win_width ] = color * texel;   }
```

☐ Should `use_eye` be ◯ `true` or ◯ `false`? ☐ Explain.

☐ Show an image of the rectangle rendered with `use_eye=true` and ☐ with `use_eye=false`. ☐ Choose a view in which the two will appear different (but the same view for both settings of `use_eye`.

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(*c*) Consider two scenes. Scene I has T triangles, Scene II has $3T$ triangles. Scene II was created by splitting each Scene I triangle into three triangles that cover the same area so that Scenes I and II appear to be identical.

☐ How would the time to render Scene II compare to the time to render Scene I on a typical rasterization pipeline (not the ray tracing pipeline below)? ◯ *About the same*, ◯ *a little more time*, or ◯ *a lot more time*. ☐ Explain.

Appearing below is our super-simple CPU-only ray-tracing code.

```
// Outer Loops (yw, xw): Iterate over each pixel.
for ( uint yw = 0;  yw < win_height; yw++ )
  for ( uint xw = 0;  xw < win_width; xw++ )
    {
      pCoor px_e = window_ll_e + window_dx_e * xw + window_dy_e * yw;
      pVect ray(px_e); // Ray From Eye to Pixel.

      float tmin = 1e10;  // Distance to closest triangle found so far.

      // Inner Loop (it): Iterate over each triangle.
      for ( auto it = coors_es.begin(); it != coors_es.end(); ) {
          pCoor e0 = *it++,  e1 = *it++,  e2 = *it++; // Get Triangle

          // Find where ray intercepts plane defined by triangle.
          pVect v01(e0,e1), v02(e0,e2);
          pVect nt = cross(v01,v02);
          float t = dot( pVect(e0), nt ) / dot( ray, nt );
          /// Remaining code not shown.
```

☐ How would the time to render Scene II compare to the time to render Scene I on the ray tracing code above? ◯ *About the same*, ◯ *a little more time*, or ◯ *a lot more time*. ☐ Explain.

☐ Explain the difference between "real" ray-tracing code and the code above which makes the previous question about Scene I and Scene II unfair.

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Problem 6: [15 pts] Answer each question below.

(a) Compute the dot product of vectors $\begin{bmatrix}1\\2\\3\end{bmatrix}$ and $\begin{bmatrix}4\\5\\6\end{bmatrix}$.

☐ $\begin{bmatrix}1\\2\\3\end{bmatrix} \cdot \begin{bmatrix}4\\5\\6\end{bmatrix} =$

(b) Compute a vector orthogonal to $\begin{bmatrix}1\\2\\3\end{bmatrix}$.

☐ A vector orthogonal to $\begin{bmatrix}1\\2\\3\end{bmatrix}$ is:

(c) Write a parametric equation of a line, $S(t)$, that passes through points P_1 and P_2 and such that $S(0) = P_1$ and $S(1) = P_2$. Also for this line find an expression $t(x_1)$ which gives the value of t for which the x component of the point is x_1.

☐ $S(t) =$

☐ $t(x_1) =$

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I had many more questions, but it's only a 2-hour exam.
The reason that this page is blank, BTW, is to provide some privacy for the answer to the last question.

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