Staple This Side

Name ______________________ *Formatted For Two-Sided Printing*

# GPU Programming
# EE 4702-1
# Midterm Exam

25 October 2023, 9:30-10:20 CDT

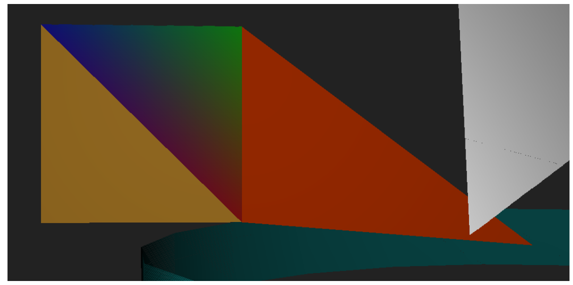
| | | |
|---|---|---|
| Problem 1 | ______ | (30 pts) |
| Problem 2 | ______ | (15 pts) |
| Problem 3 | ______ | (25 pts) |
| Problem 4 | ______ | (30 pts) |
| Exam Total | ______ | (100 pts) |

Alias ______________________

*Good Luck!*

Staple This Side

Problem 1: [30 pts] Appearing below is code to render three adjacent triangles (from left to right: gold, multicolored, and red), taken from the `World` class in the solution to Homework 3.



(*a*) The code below is set to render the three triangles as a triangle strip but the coordinates are inserted for an individual triangle grouping. Modify the code so that the coordinates are inserted for a triangle strip.

☐ In `World` insert coordinates for the three triangles using triangle-strip grouping.

(*b*) Modify the code in `World` and `Our_3D` so that the gold and red triangles retain their colors and so that the multicolored triangle is now green with the triangle-strip grouping. The changes for `Our_3D` should work for all triangle strips.

☐ In `World` insert colors for the three triangles to color are gold, green (instead of multi-colored), and red with triangle-strip grouping.

☐ Modify `Our_3D` so that triangles are gold, green, and red, instead of a blurry mess. ☐ Changes should only affect triangle strips. ☐ Only a line or two of code is needed. Don't overdo it.

```
/// Code from World::render_scene()
vector<pCoor> coors_os;   vector<pColor> colors;

// Insert white and purple triangles.
coors_os << pCoor( 0, 0, 0 ) << pCoor( 9, 6, -5 ) << pCoor( 0, 7, -3 );
colors << color_white << color_white << color_white;
coors_os << pCoor(7,2,1) << pCoor(-3,3,-3.5) << pCoor(9,0,0);
colors << color_lsu_purple << color_lsu_purple << color_lsu_purple;

gc.topology_strip_set(false).vtx_normals_set();
gc.vtx_coors_set(coors_os).vtx_colors_set(colors).draw_rasterization();
coors_os.clear(); colors.clear();
// Code above correct, don't modify.


coors_os << pCoor(-4,0,-3) << pCoor(-4,2,-3) << pCoor(-2,0,-3);
colors << color_lsu_gold << color_lsu_gold << color_lsu_gold;


coors_os << pCoor(-4,2,-3) << pCoor(-2,2,-3) << pCoor(-2,0,-3);
colors << color_blue << color_green << color_red;


coors_os << pCoor(-2,2,-3) << pCoor(-2,0,-3) << center + sz;
colors << color_orange_red << color_orange_red << color_orange_red;


// Code below correct, don't modify.
gc.topology_strip_set(true).vtx_normals_set();
gc.vtx_coors_set(coors_os).vtx_colors_set(colors).draw_rasterization();
coors_os.clear(); colors.clear();
```



Staple This Side

Staple This Side

```
/// Code from Our_3D::draw_rasterization()
for ( size_t i=0; i+2<coors_os.size(); i += ( topology_strip ? 1 : 3 ) ) {
    // Get next triangle's object- and window-space coordinates.
    pCoor o0 = coors_os[i+0],  o1 = coors_os[i+1],  o2 = coors_os[i+2];
    pCoor_Homogenized w0( ws_from_os*o0 ), w1( ws_from_os*o1 ), w2( ws_from_os*o2 );
    pColor c0 = colors[i+0],  c1 = colors[i+1],  c2 = colors[i+2];

    pNorm tn = cross(o0,o1,o2); // Compute triangle normal (for lighting).
    pVect4 n0, n1, n2;
    if ( vtx_normals ){n0=vtx_normals[i+0]; n1=vtx_normals[i+1]; n2=vtx_normals[i+2];}

    pVect v20(w2,w0), v21(w2,w1);
    float db0 = 1/max(fabs(v20.x),fabs(v20.y)), db1 = 1/max(fabs(v21.x),fabs(v21.y));

    // Iterate over triangle using barycentric coordinates.
    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;  // Fragment window-space coordinate.
          if ( uint(wf.x) >= win_width || uint(wf.y) >= win_height ) continue;
          const size_t idx = wf.x + int(wf.y) * win_width;  // Frame buffer index.

          // Depth (Z) Test
          if ( wf.z < 0 || wf.z > 1 || zbuffer[ idx ] < wf.z ) continue;
          zbuffer[ idx ] = wf.z;

          // Blend color of three vertices together.
          pColor color = b0*c0 + b1*c1 + b2*c2;

          // Find approximate object-space coordinate of fragment.
          pCoor of = b0*o0 + b1*o1 + b2*o2;

          // Compute Lighted Color
          pVect4 n = vtx_normals ? b0*n0 + b1*n1 + b2*n2 : tn;
          pNorm f_to_l(of,light_location);
          float phase = fabs(dot(n,f_to_l));
          pColor lighted_color = phase / f_to_l.mag_sq * light_color * color;

          // Write the frame (color) buffer with the lighted color
          frame_buffer[ idx ] = lighted_color.int_rgb();
          frame_buffer.n_px_frame++; // Count of number of written pixels.
        }}
```

Problem 2: [15 pts] The code below is condensed from the Homework 2 solution, in which an inner ring had to be added to an outer ring of balls. Unlike the homework solution the code below computes the position (coordinate) of a ball on the inner ring using transformation matrix `m` on the position of an outer ring ball. Add code to compute `m` so that the inner ball is placed in the correct position. *Hint: This is not that difficult.*

☐ Add code so that `m` is set to a transformation matrix that finds an inner-ball position given an outer-ball position.

```
float r_outer = si.ring_outer_radius;         // Radius of outer ring.
pCoor ctr_outer = si.center_pos;              // Center of outer ring.
pVect vx = r_outer * ax,  vy = r_outer * ay;

for ( int i=0; i<n_balls; i++ ) {             // Place balls on outer ring.
    pCoor pos = ctr_outer + vx * cosf(Δθ * i) + vy * sinf(Δθ * i);
    balls += new Ball( pos, ball_default );} // Construct ball, add to ball list.

float r_inner = 0.5f * p1p2.magnitude;        // Radius of inner ring.
pCoor ctr_inner = si.p1 + r_inner * p1p2;     // Center of inner ring.
pVect vx2 = r_inner * ax, vy2 = r_inner * ay;

if ( false ) for ( int i=0; i<n_balls; i++ ){
    // Compute Inner-Ball Position.  THIS LOOP DOESN'T EXECUTE. SHOWN FOR REFERENCE.
    pCoor pos = ctr_inner + vx2 * cosf(Δθ * i) + vy2 * sinf(Δθ * i);
    balls += new Ball( pos, ball_default ); }

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

```
pMatrix m =                                              ; // ☐  Compute m.

for ( int i=0; i<n_balls; i++ ) // "New" For This Exam
  {
    pCoor pos_outer = balls[i]->position;       // DO NOT MODIFY THIS LOOP.
    pCoor pos_inner = m * pos_outer;
    balls += new Ball( pos_inner, ball_default );
  }
```



Staple This Side

Staple This Side

Staple This Side

Problem 3: [25 pts] A scene consisting of $T = 30$ triangles is to be rendered on to a $w \times h$ pixel frame buffer with $w = h = 100$. Suppose that each triangle has an area of $A = 40$ pixels in window space. **All parts of all triangles are in the view volume.**

(*a*) In a rasterization draw for this scene, what are the maximum and minimum number of times the depth ($z$) and color buffer can be read and written. (The color buffer is where the pixel is written.) Explain.

☐ Answers below should be in terms of $T$, $A$, $w$, and $h$.

☐ Max number of depth buffer reads:

☐ Min number of depth buffer reads:

☐ Max number of depth buffer writes:

☐ Min number of depth buffer writes:

☐ Max number of color buffer reads:

☐ Min number of color buffer reads:

☐ Max number of color buffer writes:

☐ Min number of color buffer writes:

☐ Briefly explain difference between maximum and minimum cases.

(*b*) In a ray tracing draw, how many times will the color (frame) buffer be read and written for this scene? Explain.

☐ Answers below should be in terms of $T$, $A$, $w$, and $h$.

☐ Max number of color buffer reads:

☐ Min number of color buffer reads:

☐ Max number of color buffer writes:

☐ Min number of color buffer writes:

(*c*) Our CPU-only ray-tracing code included a ray/triangle intersection test:

```
pVect v01(e0,e1), v02(e0,e2); // Find where ray intercepts plane defined by triangle.
pVect nt = cross(v01,v02);
float t = dot( pVect(e0), nt ) / dot( ray, nt );
// t indicates distance from eye to intercept point in units of ray lengths.

// Skip this triangle if a closer triangle already found.
if ( t >= tmin ) continue;
```

☐ For the scene above, how many times is this intersection test done by *our* CPU-only code in terms of $T$, $A$, $w$, and $h$.

Staple This Side

Problem 4: [30 pts] Answer each question below.

(*a*) The code below from our CPU-only ray tracing demo finds the intersection of `ray` with the plane defined by a triangle. Show the number of arithmetic operations for each line, using the three categories: add, multiply & multiply-add, and divide. (Count subtract as an add, and count multiply-subtract as a multiply add.)

```
float find_intercept(pCoor e0, pCoor e1, pCoor e2, pVect ray) {

// Number of  [ ] Add & sub:          [ ] Mult & Mult-Add:          [ ] Divisions:
  pVect v01(e0,e1), v02(e0,e2);


// Number of  [ ] Add & sub:          [ ] Mult & Mult-Add:          [ ] Divisions:
  pVect nt = cross(v01,v02);


// Number of  [ ] Add & sub:          [ ] Mult & Mult-Add:          [ ] Divisions:
  float t = dot( pVect(e0), nt ) / dot( ray, nt );

  return t;
}
```

(*b*) Show the result of assignment of each line below.

```
vec4 p = vec4(1,2,3,4);  //  [✓]  p = {1,2,3,4}

vec2 qa = p.xy;          //  [ ]  qa =

vec2 qb = p.xx;          //  [ ]  qb =

vec2 qc = p.ba;          //  [ ]  qc =
```

(*c*) In graphics (classic OpenGL) terminology there is a distinction between a material property and a lighted color.

☐ What is the difference between a material property and a lighted color?

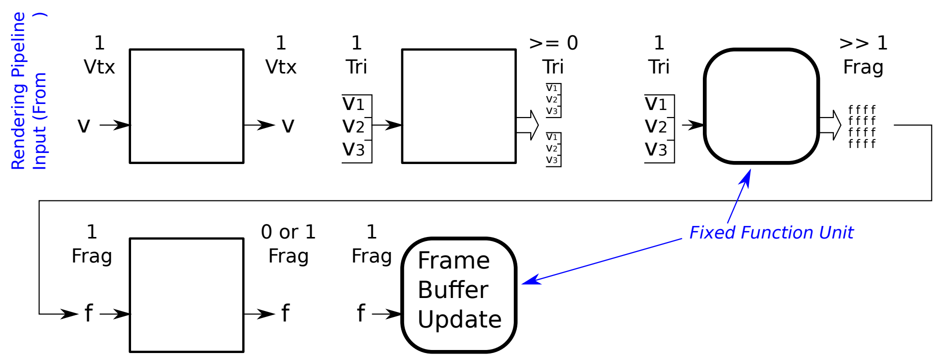
☐ The frame buffer should be written with one of these two items. How could one tell if the wrong one of these two were written?



Staple This Side

Staple This Side

(*d*) Illustrated below is a diagram of a Vulkan/OpenGL graphics (rendering) pipeline with many labels omitted.




☐ Label each stage of the pipeline.

☐ At the start of the pipeline there is a label "Rendering Pipeline Input (From )". The words after *From* are omitted. What should follow the word *From*?

☐ There is a label "Fixed Function Unit" in the diagram. What does that mean?

(*e*) Answer the following questions about shader stages used in a triangle list (not strip) vertex ordering.

☐ Which usually gets executed more frequently, a ◯ *vertex shader* or a ◯ *fragment shader* ?

☐ Explain.

☐ A scene has one triangle. Explain a situation, perhaps in terms of the eye location, in which the number of vertex shader invocations will be three times the number of fragment shader invocations.