CS195V Week 3

GLSL Programming

Differences in OpenGL and GLSL 4.x

- A lot of changes made to GLSL 4.x spec (see: http://www.opengl.org/registry/doc/GLSLangSpec.4.00.8.clean.pdf)
- CS123 used OpenGL 2.x and GLSL 1.x
- IMPORTANT: OpenGL 4.x requires a relatively new GPU (nVidia 400 series or higher, AMD Radeon 5000 series or higher)
  - Most of the computers in the CS labs should be okay, but if you are working from home, check your graphics card
- When writing your shaders you should specify your target by adding the preprocessor definition (ex. #version 400 core to specify GLSL version 4 core specification)
  - Instead of core, you can specify compatibility, which gives you access to the old defined variables (ex. gl_ModelViewMatrix) - don't use this!

GLSL 4.x Important Changes

- The user is responsible for maintaining the matrix stack (no more gl_ProjectionMatrix)
    - These are passed in using uniform variables or buffers
- No more builtin variables attributes - all values are specified by the user
    - the **in** keyword specifies input variables to a shader, the **out** keyword specifies output variables **inout** is a combination of the two

```
#version 400 core
uniform mat4 modelviewMatrix;
uniform mat4 projMatrix;


// vertex shader
in vec3 in_Position;
in vec3 in_Normal;
in vec3 in_TexCoord;
void main(void) {
gl_Position = projMatrix *
modelviewMatrix * vec4(in_Position,1.0);
}


// fragment shader
out vec4 out_Color;
void main() {
out_Color = vec4(1.0,1.0,1.0,1.0);
}
```

GLSL 4.x Important Changes

- Make sure to specify a #version at the top
  - For most of this class, this should be #version 400 core
  - If you do not specify a version, it will assume #version 110 - this is not what you want to do
  - We might make use of extensions later using the #extension directive
- It is possible to specify the precision of any floating point or integer declaration by preceding it with □**highp mediump** or **lowp**
  - To set the default position you can use
    precision [qualifier] [type]
    ex. precision highp float;
- If you use high precision, you probably want to use the **precise** qualifier which ensures a specific order of operations (and thus consistent precision)

Texture Samplers

Texture samplers have changed a bit since GLSL1.x...here are some of them:

- texture(sampler, tc)
  regular texture lookup function (no more texture2D)
- textureLod(sampler, tc, lod)
  same as above, but you can choose the lod
- textureOffset(sampler, tc, offset)
  same as texture, except adds offset before sampling
- texelFetch(sampler, pos, lod)
  same as textureLod, except everything is integer valued (useful for sampling from specific texels)

Texture Gathers

- New in GL 4.0
- Gather functions take a sampler and texture coordinate and then determine a set for four texels to sample from
  - Then returns one component from each texel in a 4 component result vector
- textureGather, textureGather, textureGatherOffsets....
- textureGatherOffsets
  - probably the most interesting one for us
  - gvec4 textureGatherOffsets(sampler2D, tc, ivec2 offsets [4], [int comp])
  - if comp is specified it must be 0,1,2, or 3 specifying which component to gather from each texel (x,y,z, or w)

Last Word on Sampling

- Texture sampling is a relatively expensive operation - a lot needs to happen internally for a texture sample to go through
  - Try to minimize # of sampling calls when possible
- How expensive is it?
  - Consider the game of life - we need to sample from the 8 neighboring pixels and ourself - so let's say we do this using one texture call for each pixel in our fragment shader
  - Thats 9 texture calls per pixel - which means sending 9 u,v texture coordinates (18 floats) x 4 = 72 bytes
  - Assume we have 1k x 1k grid (texture)
  - So for each pass we process 1 * 72 million bytes
  - Say we want 30fps - thats 1*72*30 = 2.012 GB /s throughput (just for texture requests!)
- Keep in mind the texture samplers aren't part of the hardware shader cores - they are separate units on the GPU - so this data needs to be shuffled back and forth

Last Word on Sampling (Continued)

- Yeah ok, thats a lot of memory bandwidth - but what happens when the request reaches the sampler?
    1. Calculate texture gradients
    2. Calculate mip level
    3. Apply address modes (wrap / clamp...)
    4. Convert the [0..1] coordinates to sample form needed by the hardware (fixed point)
    5. Compute the address to read texels from
    6. Filter - this is 4 memory accesses for bilinear :(
    7. Ok it's more like about 1.25 accesses because of caching
    8. Finally send back up to 4 texture values

Uniform Buffers

- It is possible to set uniform variables in one block instead of one at time
  - Switching one block is faster than switching several different uniforms separately
  - Buffer blocks can also be shared between programs
  - Note that each shader stage has a limit on the number of block locations (GL_MAX_[stage]_BLOCKS)

```
layout(shared) uniform BlockName {
  vec3 blockMember1, blockMember2;
  float blockMember3;
};
```

- In GL, use glGetUniformBlockIndex and glUniformBlockBinding

Uniform Block Layout Qualifiers

- Because uniform buffers are defined by you, GL doesn't know the layout
  - layout tells GL to access and load each component within the block and must be either std140, packed, or shared
- packed tells the implementation how to layout the fields and therefore you must query GL for the byte offsets of each block when you upload the data
  - if you want to share data between programs don't use this, use shared instead (duh) - why?
- if you want to specify your own layout use std140 - you probably won't need to do this for this class

Multiple Render Targets

- At times, it may be useful to write to more than one color buffer in one fragment pass - in old GLSL, this was accomplished with gl_FragData[idx]
- Now you must bind your output locations (similar to how you bind the vertex attributes)
  void **glBindFragDataLocation**
  (GLuint program, GLuint colorNumber, const char
  * name);
- The support code provides ShaderProgram::
  setFragDataLocation which simply wraps around this call
- Don't forget to bind a framebuffer with multiple color attachments when using MRT
  - Easily done by changining nColorAttachments in FramebufferObjectParams

Input Layout Qualifiers

- Remember from last class when we had to query our shader to determine the IDs of our vertex attributes (ie. what's the id of in_Normal?)
- It's possible to explicitly specify this in the shader
  - For example:
    layout(location = 3) in vec3 in_Normal;
    layout(location = 4) in vec4 colors[3];
- Why would you do this?
  - You don't need to ask GL for their locations anymore...
- In GL4.2 (which was revealed at SIGGRAPH 2011) you can also specify the location of a unform block index
  - Slight caveat: I don't think the cs gfx drivers support 4.2 yet...so you need to use #extension

```
#version 420 //#extension GL_ARB_shading_language_420pack
layout(std140, binding=5) uniform SomeBlock { ... };
```

Instanced Drawing

- Say you want to draw a whole bunch of one kind of primitive
  - Array of cubes, etc.
- You could call draw() on the primitive a whole bunch of times, but it is faster to call glDrawInstanced(int n)
- This will draw the given primitive n times
- In the vertex shader, you will have access to gl_InstanceID, which goes from 0 to n - 1
- You can use this to transform different primitives in different ways
- This might be useful for visualizing something like a Life simulation...

Geometry Shaders

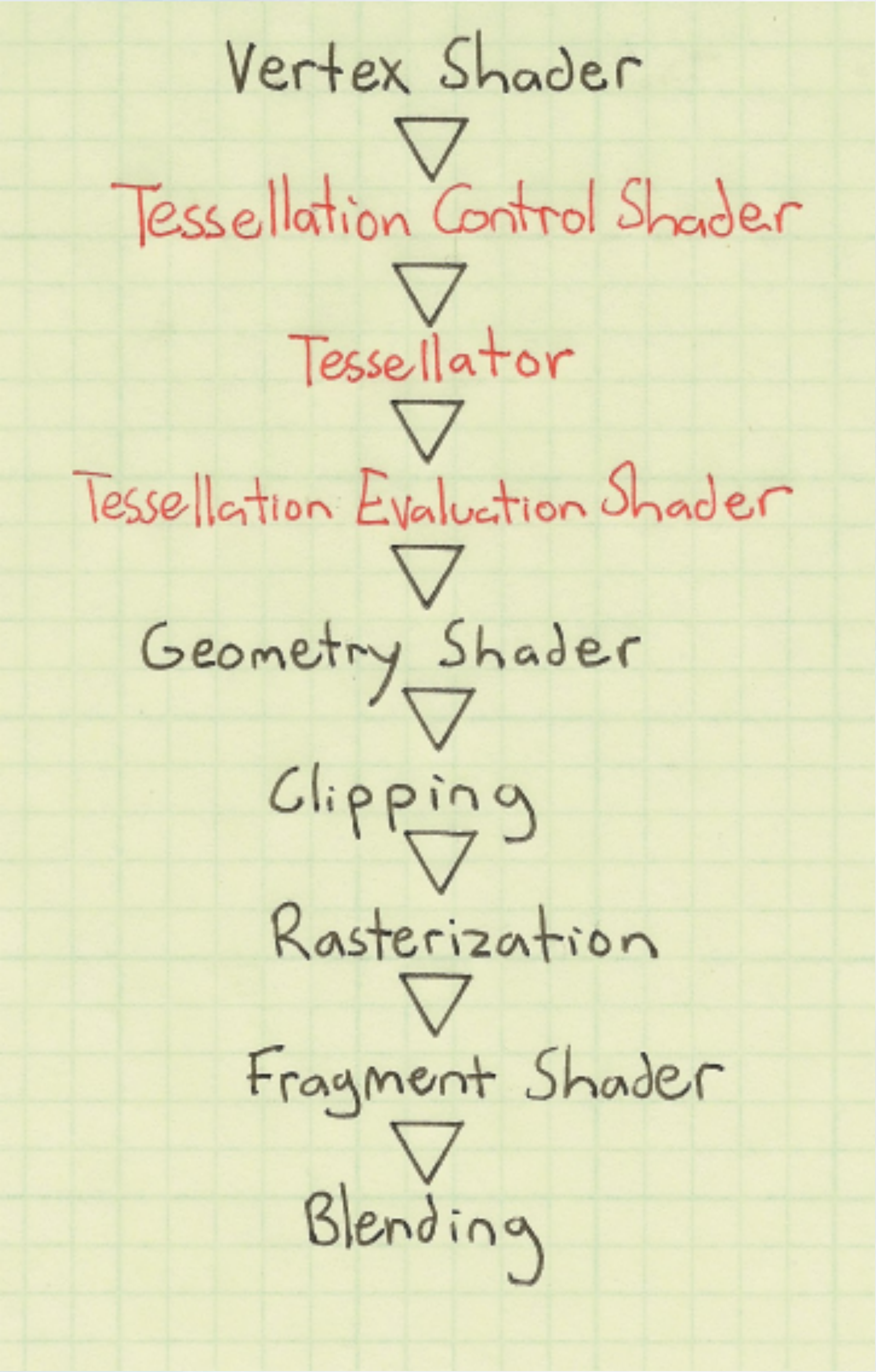
- Shader stage that operates on entire primitives (points, lines, triangles)
- Can create new primitives (as opposed to vertex shaders which cannot)
- Even in situations where you don't want to make new primitives, being able to see all vertices in a primitive can yield useful computations
- Examples
    - nVidia Fermi hair demo: simulates hair as line segments, then draws them using triangles
    - Useful for particle simulations where you want to do calculations on points but draw something else
    - Various games use geometry shaders for motion blur and depth of field effects

A Trivial Geometry Shader (Triangles)

```
layout(triangles) in;
layout(triangle_strip, max_vertices = 3) out;
void main() {
    for(int i = 0; i < gl_in.length(); i++) {
        gl_Position = gl_in[i].gl_Position;
        EmitVertex();
    }
EndPrimitive();
}
```

Tessellation Shaders

- Adds two new programmable stages to the shader pipeline: Tessellation Control and Tessellation Evaluation
  - Called Hull Shader and Domain Shader in D3D
- In between them is a fixed function unit called a Tessellator which generates new vertices
- Tessellation Control is similar to a vertex shader but has knowledge of the entire primitive
  - It sets up input parameters which tell the Tessellator how to generate new vertices
- Tessellation Evaluation then operates on the output vertices of the Tessellator
- This addition has been put into use in dynamic level of detail on complex models
- Can also be used to do frustum culling



Tessellation Shaders

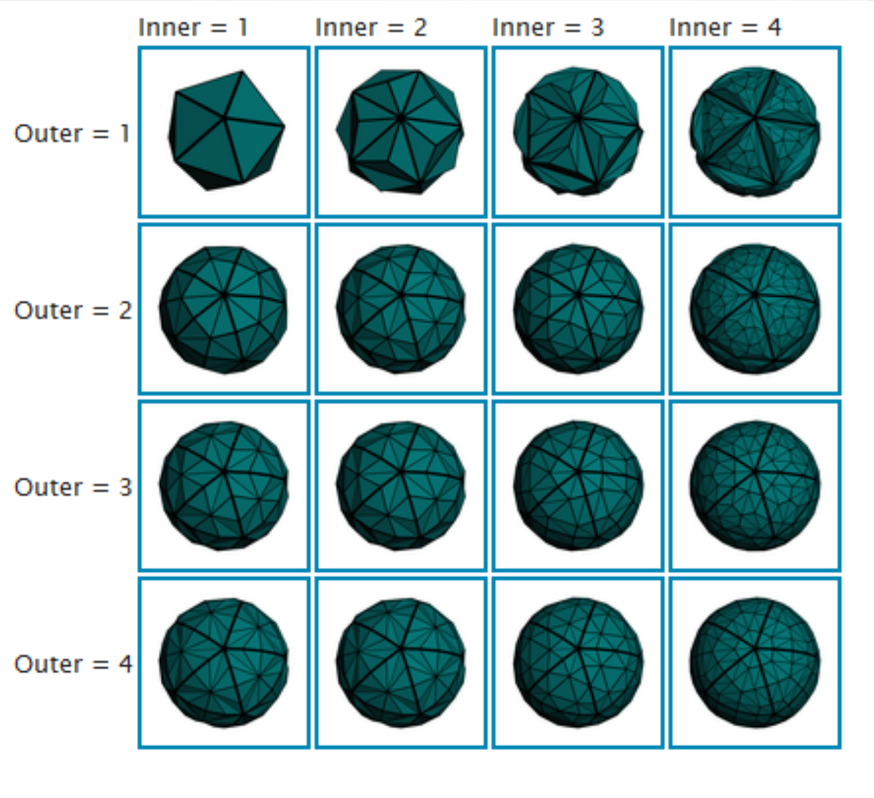
- To use tessellation shaders, there is a new primitive type - GL_PATCHES, unlike other primitive types (GL_TRIANGLES), you can specify the number of vertices

```
// tell OpenGL that every patch has 16 verts
glPatchParameteri(GL_PATCH_VERTICES, 16);      // draw a bunch of patches
glDrawArrays(GL_PATCHES, firstVert, vertCount);
```

- Layout
  - In the shader, you must define how many vertices in a tessellation primitive (3 for triangle, 4 for quad, etc)

Tessellation Control

- Important variables: gl_TessLevelInner and gl_TessLevelOuter
- Specifics differ depending on what kind of primitive you are using
- In general, inner defines how many "nested primitives" to generate and outer defines how many times to subdivide each edge
- These parameters will determine what the Tessellator outputs
- This is how you control LoD!



Tessellation Evaluation

- Executes once per vertex output by the Tessellator
- You have access to the original primitive vertices and a Tessellation Coordinate
  - For triangles, Barycentric coordinates
  - For quads, uv coordinates
- Here is where you would set the final position of the tessellated vertex
- Important Variables
  - gl_PatchVerticesIn - # of verts in the input patch
  - gl_TessLevelInner/Outer - inner and outer tess values
  - gl_TessCorrd - coordinates in the patch domain space

A Simple Example

```
-- Vertex
in vec3 in_Position;
out vec3 vPosition;
void main()
{
    vPosition = in_Position;
}

-- TessControl
layout(vertices = 4) out;
in vec3 vPosition[];
out vec3 tcPosition[];
uniform float TessLevelInner;
uniform float TessLevelOuter;

#define ID gl_InvocationID

void main() {
tcPosition[ID] = vPosition[ID];
    if (ID == 0) {
        gl_TessLevelInner[0] = TessLevelInner;
        gl_TessLevelInner[1] = TessLevelInner;
        gl_TessLevelOuter[0] = TessLevelOuter;
        gl_TessLevelOuter[1] = TessLevelOuter;
        gl_TessLevelOuter[2] = TessLevelOuter;
        gl_TessLevelOuter[3] = TessLevelOuter;
    }
}
```

- gl_InvocationID tells us the current vertex we're on
    - We only need to set patch parameters once per patch hence the if()

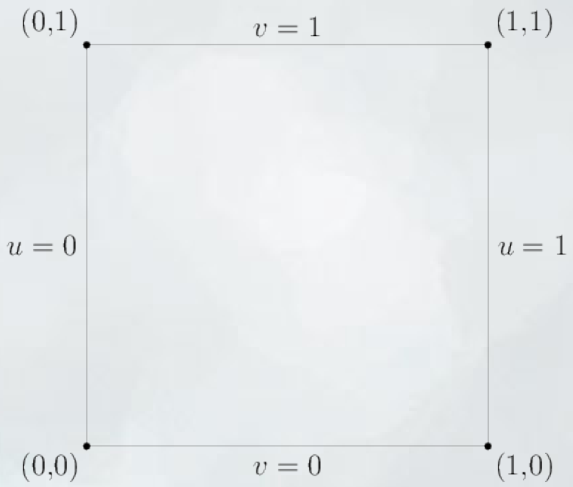
A Simple Example

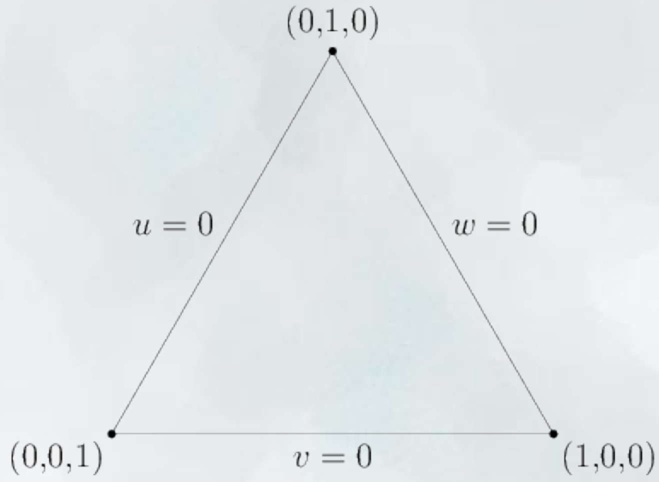
```
-- TessEval
layout(quads, fractional_odd_spacing, ccw) in;
in vec3 tcPosition[];
uniform mat4 projMatrix;
uniform mat4 modelviewMatrix;
void main()
{
    float u = gl_TessCoord.x, v = gl_TessCord.y;
    vec3 a = mix(tcPosition[1], tcPosition[0], u);
    vec3 b = mix(tcPosition[2], tcPosition[3], u);
    vec3 tePosition = mix(a, b, v):
    gl_Position = projMatrix * modelviewMatrix * vec4(tePosition, 1);
}
```

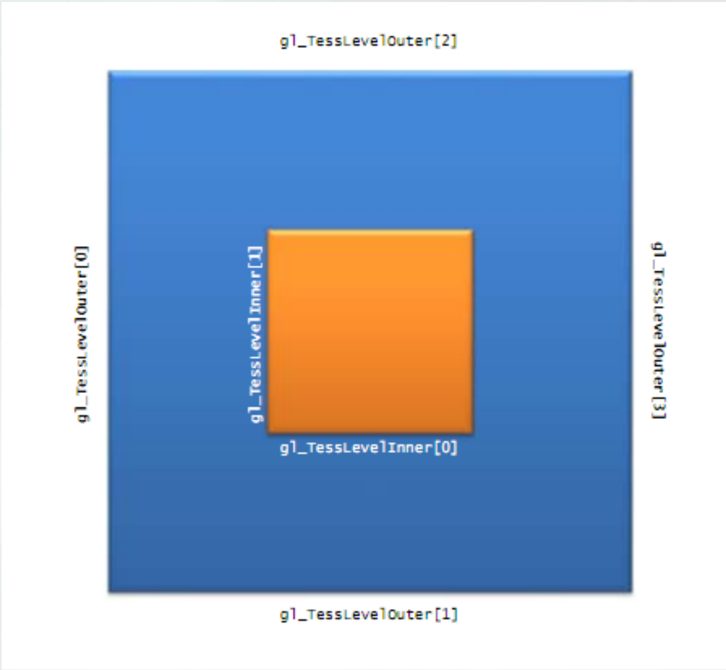
```
out vec4 out_Color;
void main()
{
    out_Color = vec4(1.0);
}
```

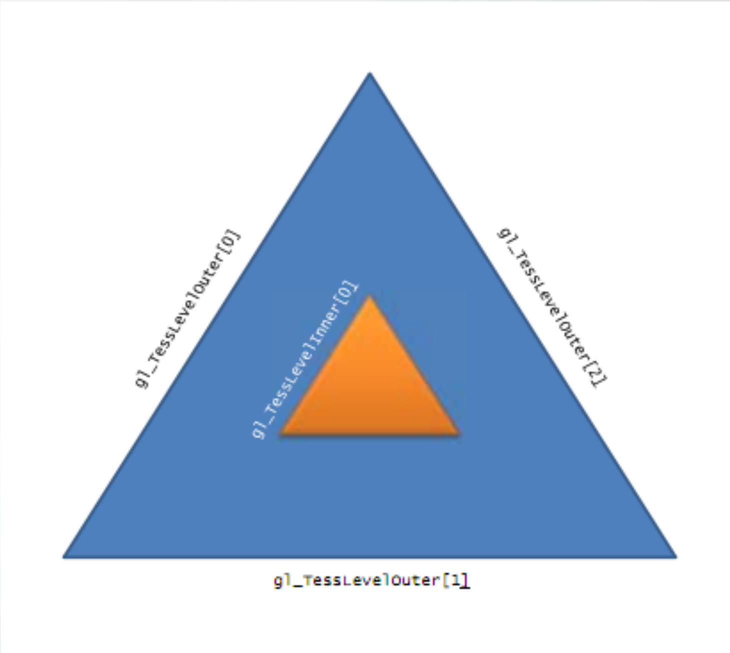
Note that since we are doing quad subdivision, the gl_TessCoord corresponds to u, v coordinates, as opposed to barycentric coordinates for triangle subdivision

Quads vs Triangles



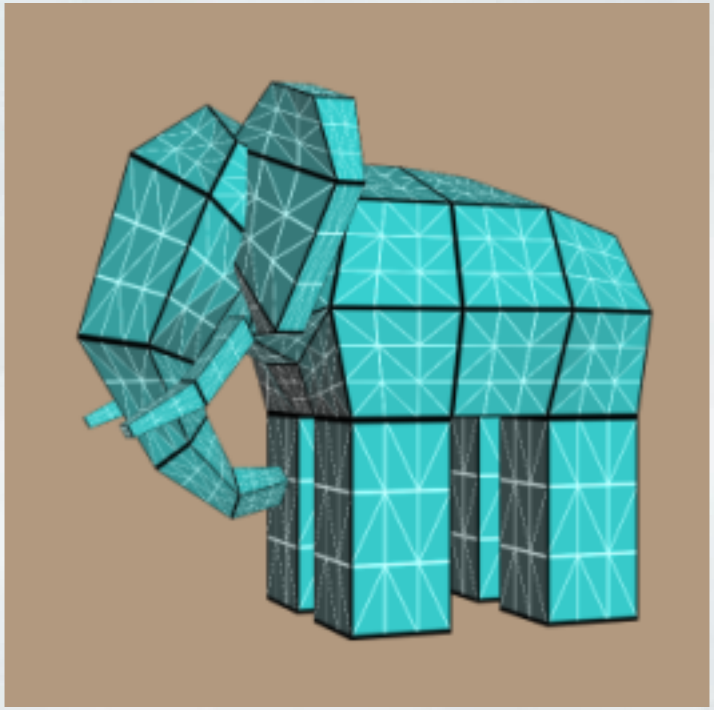




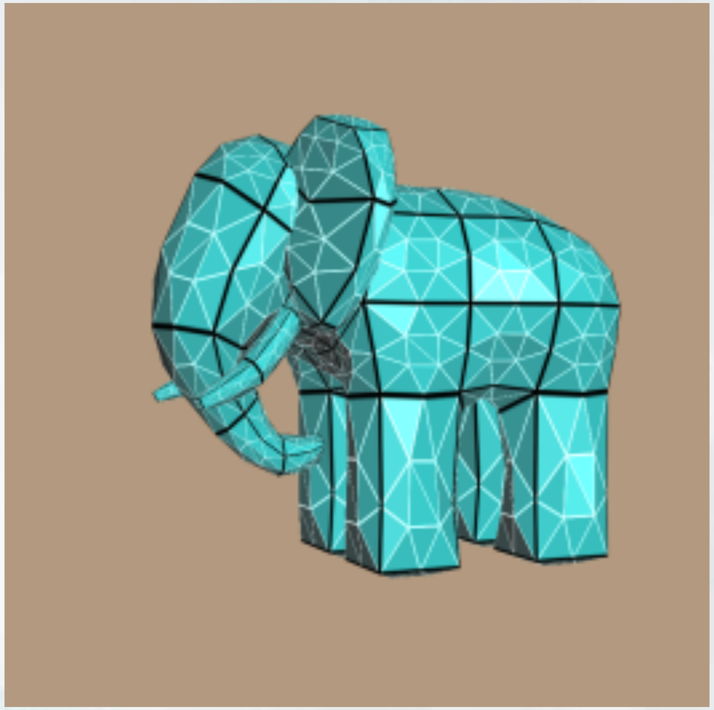


A Simple Example

- Note that more complex tessellation schemes are possible
- ex. Bezier smoothing / interpolation of vertices
  - Maybe want to created a smoothed surface instead of a surface with sharp corners



vs



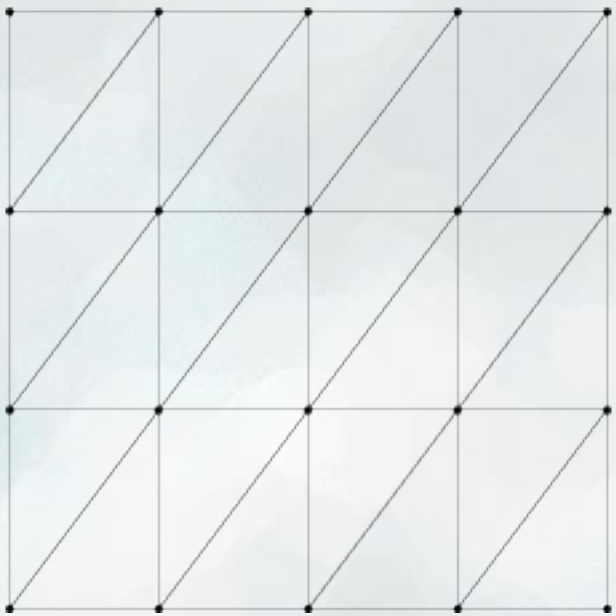
http://developer.download.nvidia.com/presentations/2010/gdc/Tessellation_Performance.pdf

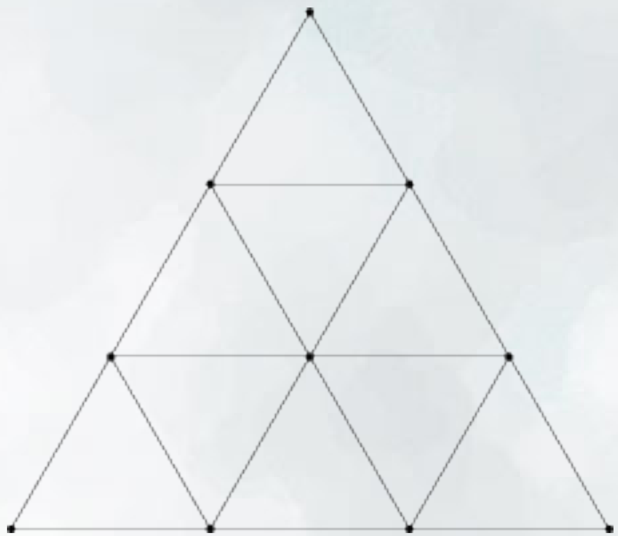
Input Layout Qualifiers for TC and TE

- You may have noticed input layout qualifiers for tessellation shaders are somewhat different from everything else
- For the TC stage:
  layout(vertices = [#]) out;
- For the TE stage:
  layout([type], [spacing], [order]) in;
  - recall [type] specifies primitive type (ex. quads, triangles, or isolines)
  - spacing - see next slide
  - order specifies vertex ordering (cw or ccw)

Tessellation Shader Details

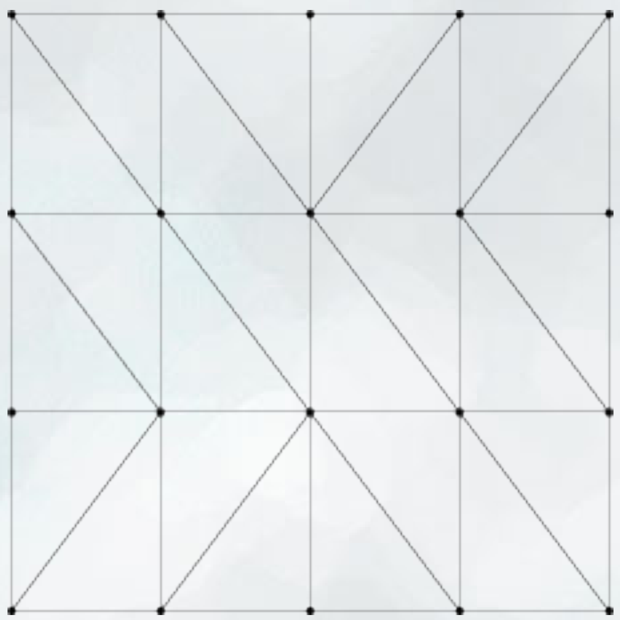
- Given a single triangle or quad, a natural way to tessellate it would look like this:

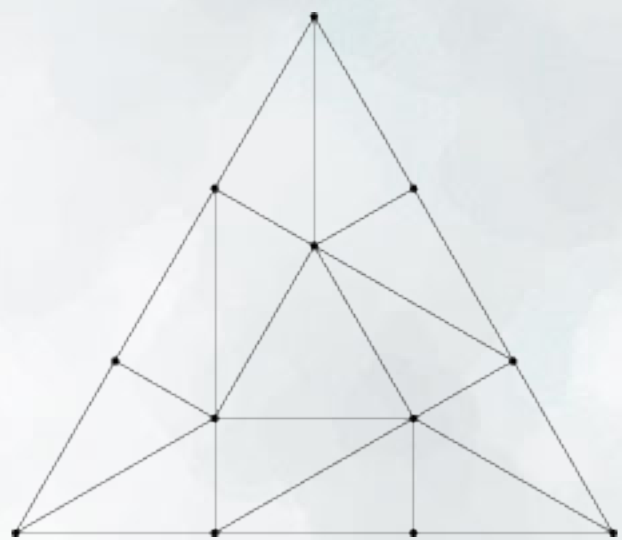




Tessellation Shader Details

- But graphics is never that easy. Instead the GPU spits out out something like this:





What's going on?

- The weird looking tessellation arises because of the way transitions between patches at different tessellations are handled (recall the inner and outer tess levels)
- When tessellating geometry, it is important that if two patches share an edge, they should compute the same tessellation factors along that edge (the outer tess level)
    - Otherwise you will get holes in your mesh
    - This can get very annoying at times
- The GPU doesn't care if your mesh has holes or not - if you did it right, you won't
- If you did it wrong, you will and it's now your problem
- All that this weird ordering guarantees is that it is *possible* to create a watertight mesh...

Spacing!

- By default, the tessellator will jump from integer to integer tessellation values
- By specifying a spacing (ex. fractional odd or fractional even), we can change this behavior - new vertices will appear at the same position as an existing vertex and gradually move to their final position
  - Allows for smooth transitions and prevents vertices popping in and out
  - This is probably what you want to use (it looks cool too)

Output Layout Qualifiers

- Vertex and TE shaders cannot have output layout qualifiers
- TC shaders:
    - specifies # of vertices in the patch output by the TC shader
    - layout-qualifier-id vertices = [#verts]
    - ex. layout(vertices = 3) out;
- Fragment shaders:
    - you can specify the bind location of each output
    - layout(location = 3) out vec4 out_Color0;

One Last Word about Qualifiers

- When you specify multiple qualifiers, they must follow a specific order:
  [precise] [invariant] [interpolation] [storage] [precision]
  [storage] [parameter] [precision]
- Qualifiers are good to know about, but you don't have to use them for most simple use cases
  - Most only really matter when you really care about performance

Example : Frustum Culling

```
layout(vertices = 4) out;
in vec3 vPosition[];
out vec3 tcPosition[];
uniform float TessLevelInner;
uniform float TessLevelOuter;
bool offscreen(vec4 vertex){
    if((vertex.z < 0.0)) return true;
    return any(lessThan(vertex.xy, vec2(-1.0)) ||
           greaterThan(vertex.xy, vec2(1.0)));
}
void main() {
    tcPosition[gl_InvocationID] = vPosition[gl_InvocationID];
    if (gl_InvocationID == 0) {
mat4 pmv = projMatrix*modelviewMatrix;
vec4 ss0 = pmv*vec4(vPosition[0],1.0);
vec4 ss1 = pmv*vec4(vPosition[1],1.0);
vec4 ss2 = pmv*vec4(vPosition[2],1.0);
vec4 ss3 = pmv*vec4(vPosition[3],1.0);
ss0 /= ss0.w;
ss1 /= ss1.w;
ss2 /= ss2.w;
ss3 /= ss3.w;
if(all(bvec4(offscreen(ss0),
    offscreen(ss1),
    offscreen(ss2),
    offscreen(ss3)
))){
    gl_TessLevelInner[0] = 0;
    gl_TessLevelInner[1] = 0;
    gl_TessLevelOuter[0] = 0;
    gl_TessLevelOuter[1] = 0;
    gl_TessLevelOuter[2] = 0;
    gl_TessLevelOuter[3] = 0;
}
else {
        ...
}
    }
}
```

- Frustum culling is very easy in the TC shader
- Just check if the vertices of the patch fall off the screen
  - Set tessellation level to zero if they do

Example: Icosahedron

- Say we want to make a sphere (approximated with many small triangles)
  - However, we don't want to store all of the vertices of the sphere and we're too lazy to do the whole tessellation business from CS123 Shapes
- We have a simple icosahedron
  - 20-faced 3D polygon
  - Okay maybe it's harder to generate than the sphere but still...
  - Starting with a low detail model and tessellating on the GPU is faster than just using a higher detail model
- We can tessellate the icosahedron into a sphere-like shape

Icosahedron Vertex Shader

```
#ifdef _VERTEX_
in vec3 in_Position;
in vec3 in_Normal;
in vec3 in_TexCoord;
out vec3 vPosition;

void main() {
    vPosition = in_Position;
}
#endif
```

Note that we don't do the screen space transformation (projection * modelview) yet, since we want our tessellated vertices to be in object space, not screen space

Icosahedron Tessellation Control

```
#ifdef _TESSCONTROL_
layout(vertices = 3) out;
in vec3 vPosition[];
out vec3 tcPosition[];

#define ID gl_InvocationID

void main() {
    tcPosition[ID] = vPosition[ID];
    if(ID == 0) {
        gl_TessLevelInner[0] = innerTess;
        gl_TessLevelOuter[0] = outerTess;
        gl_TessLevelOuter[1] = outerTess;
        gl_TessLevelOuter[2] = outerTess;
    }
}
```

Similar to the simple quad example we have from before, but one inner tessellation level instead of two, and three outer tessellation levels (one for each side)

Icosahedron Tessellation Evaluation

```
#ifdef _TESSEVAL_
layout(triangles, equal_spacing, ccw) in;
in vec3 tcPosition[];
uniform float radius;
out vec3 tePosition;
out vec3 tePatchDistance;

void main() {
    vec3 p0 = gl_TessCoord.x * tcPosition[0];
    vec3 p1 = gl_TessCoord.y * tcPosition[1];
    vec3 p2 = gl_TessCoord.z * tcPosition[2];
    tePatchDistance = gl_TessCoord;
    tePosition = normalize(p0 + p1 + p2) * radius;
    gl_Position = projMatrix * modelviewMatrix * vec4(tePosition, 1);
}
#endif
```

The gl_TessCoord is a barycentric coordinate that lets you interpolate between the original triangle vertices
By normalizing and multiplying by radius, you correctly place your vertices along the curvature of the circle

Icosahedron Geometry Shader

```
#ifdef _GEOMETRY_
layout (triangles) in;
layout (triangle_strip, max_vertices = 3) out;
in vec3 tePosition[3];
in vec3 tePatchDistance[3];
out vec3 gFacetNormal;
out vec3 gPatchDistance;
out vec3 gTriDistance;

void main(){
    vec3 avg = (tePosition[0] + tePosition[1] + tePosition[2]) / 3;
    gFacetNormal = normalize(avg);

    gPatchDistance = tePatchDistance[0];
    gTriDistance = vec3(1, 0, 0);
    gl_Position = gl_in[0].gl_Position;
    EmitVertex();

    gPatchDistance = tePatchDistance[1];
    gTriDistance = vec3(0, 1, 0);
    gl_Position = gl_in[1].gl_Position;
    EmitVertex();

    gPatchDistance = tePatchDistance[2];
    gTriDistance = vec3(0, 0, 1);
    gl_Position = gl_in[2].gl_Position;
    EmitVertex();

    EndPrimitive();
}
```

Even though we don't generate any new geometry here, we can do useful things like calculate per-facet normals and add barycentric coordinates for the newly tessellated triangle

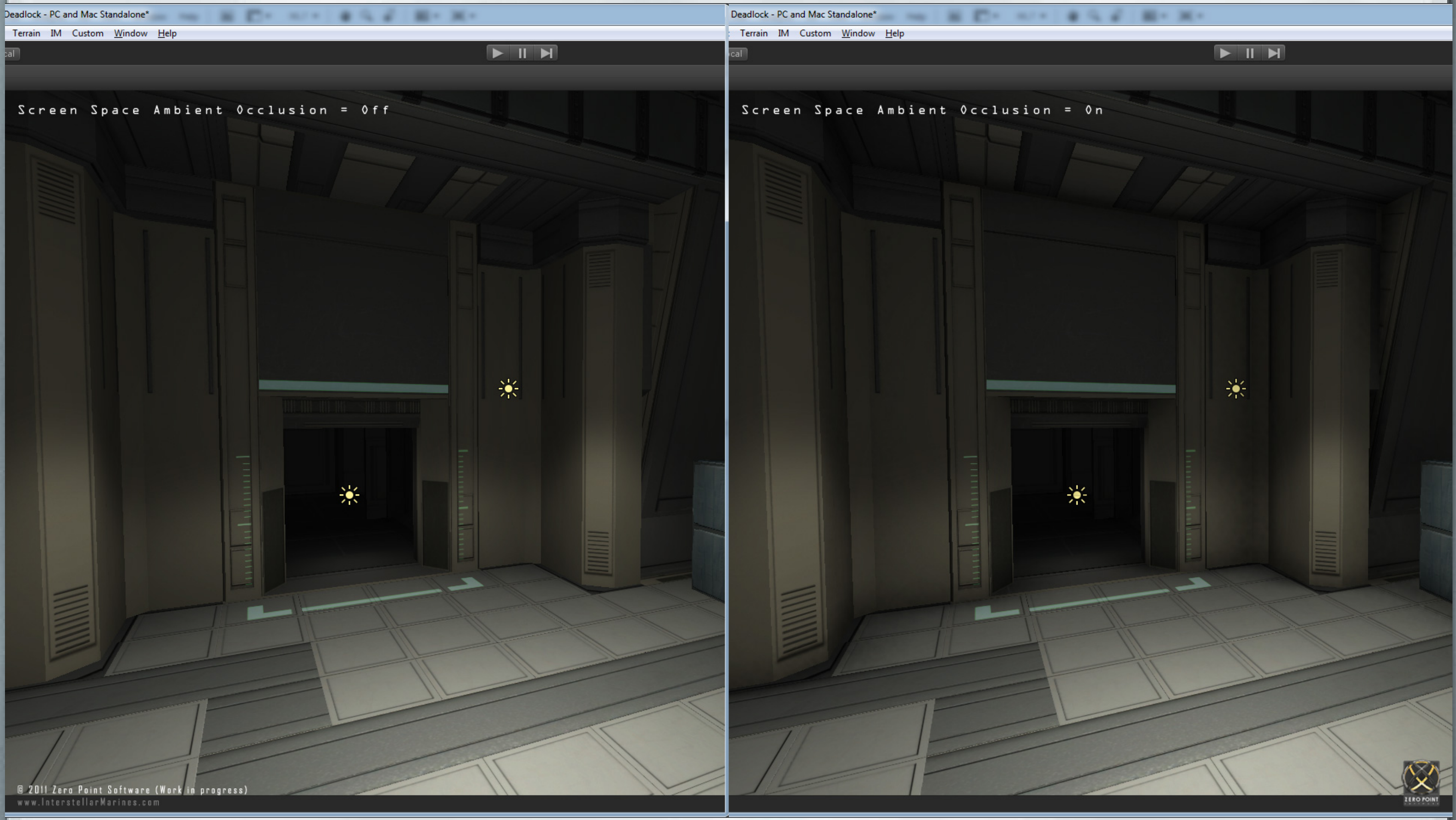
Icosahedron Fragment Shader

```
#ifdef _FRAGMENT_
in vec3 gFacetNormal;
in vec3 gPatchDistance;
in vec3 gTriDistance;
out vec4 out_Color;

float edge(float d, float scale, float offset){
    d = scale * d + offset;
    d = clamp(d, 0, 1);
    d = 1 - exp2(-2*d*d);
    return d;
}

void main(){
    float d1 = min(min(gTriDistance.x, gTriDistance.y), gTriDistance.z);
    float d2 = min(min(gPatchDistance.x, gPatchDistance.y), gPatchDistance.z);
    vec3 color = edge(d1, 40, -0.5) * edge(d2, 60, -0.5) * vec3(0.5, 0.5, 0.5);
    out_Color = vec4(color, 1.0);
}
#endif
```

Fun trick here, add smooth wireframes based on distance from the edge (check out http://dl.acm.org/citation.cfm?id=1180035)



Case Study: Screen Space Ambient Occlusion

Case Study: Screen Space Ambient Occlusion (SSAO)

- Ambient occlusion: adjusting ambient lighting contribution based on local geometry
  - Places hard for indirect illumination to reach should have a smaller ambient component
- Screen Space Ambient Occlusion
  - Approximation of ambient occlusion using only frame buffer data
  - First used in Crysis in 2007

SSAO

- For true ambient occlusion, you need information about the local geometry surrounding a particular point
  - Such data is not readily available in the rasterization pipeline
- In SSAO, use the Z-buffer (depth buffer) to partially recover some of this information
  - Not a perfect representation of geometry, but cheap and already implemented for depth testing

SSAO

1. Given your point, sample some additional points in a sphere around it
   - Tradeoff between speed and effect quality
2. Compare these sampled points to the Z-buffer, more points behind means more occlusion
3. Calculate the ambient term using these occlusion measures, taking into account distance from the actual sample point

Advantages and Disadvantages

- Good
  - Independent of scene complexity/movement
  - No additional memory required
  - Completely on the GPU
- Bad
  - Dependent on view since scene is projected into depth map
  - Can have noise and odd behavior depending on how you sample
    - To deal with this, the SSAO results are often blurred

For More details...

http://www.drobot.org/pub/GCDC_SSAO_RP_29_08.pdf