GLSL Geometry Shaders

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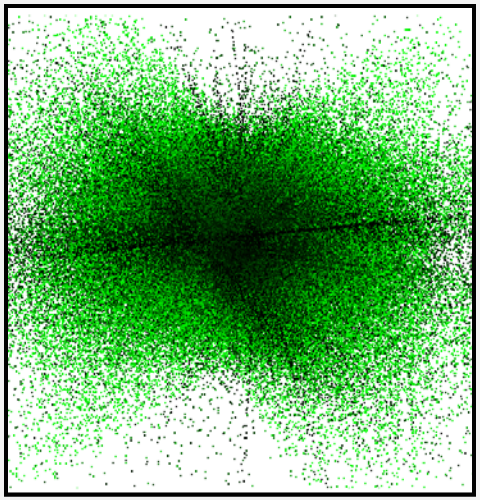
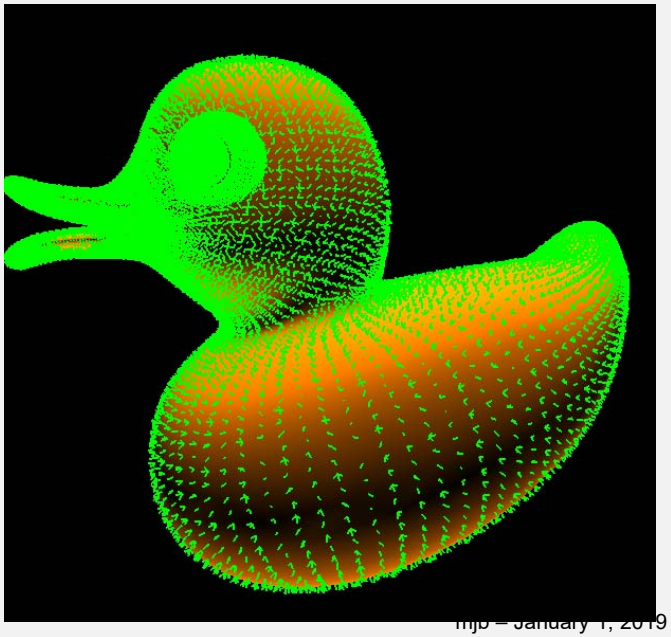
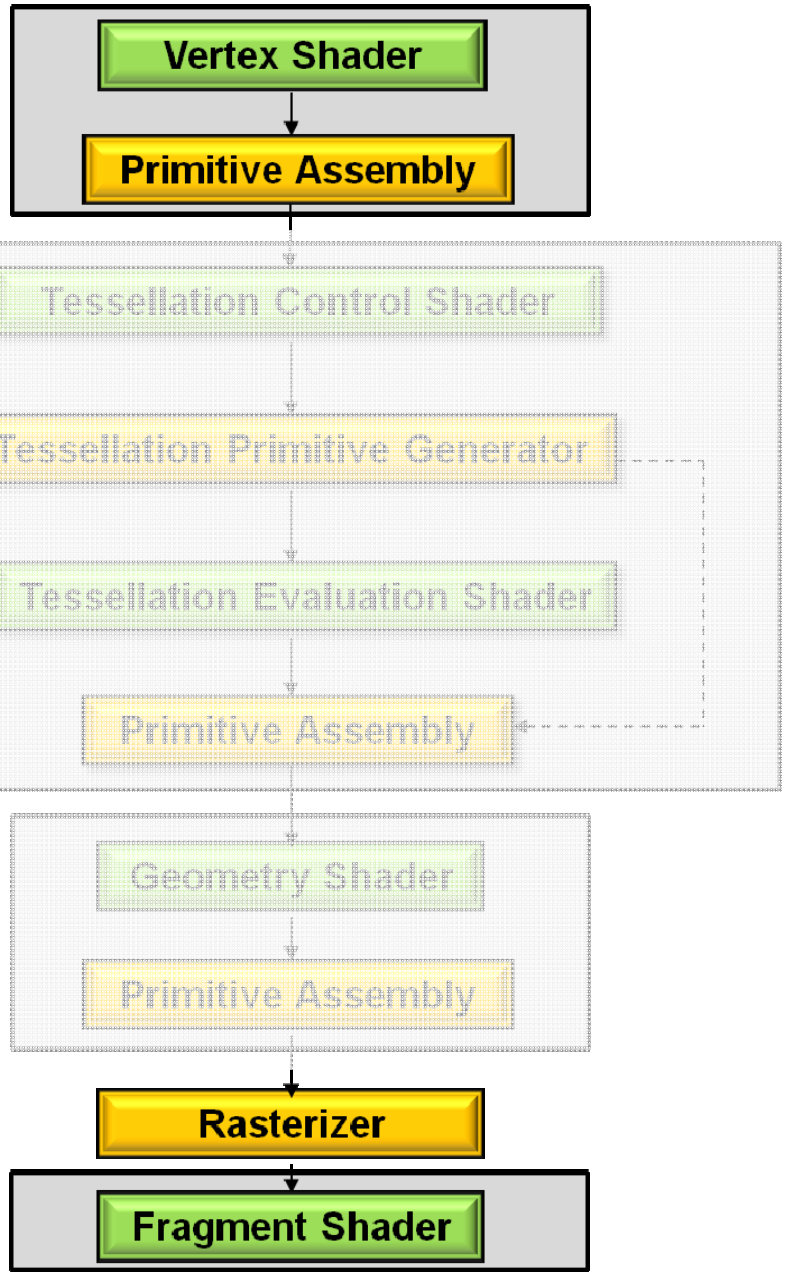




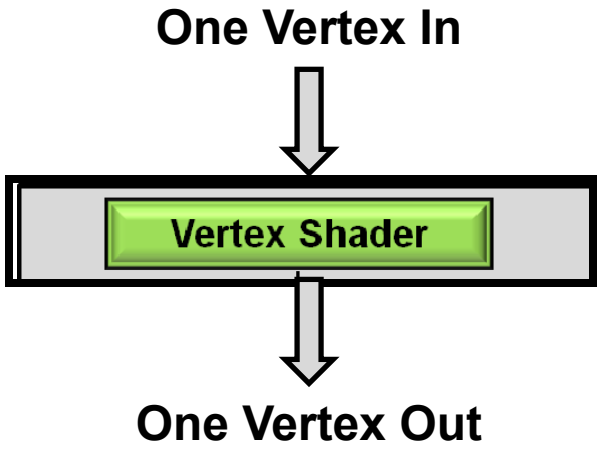
Here's What We Know So Far



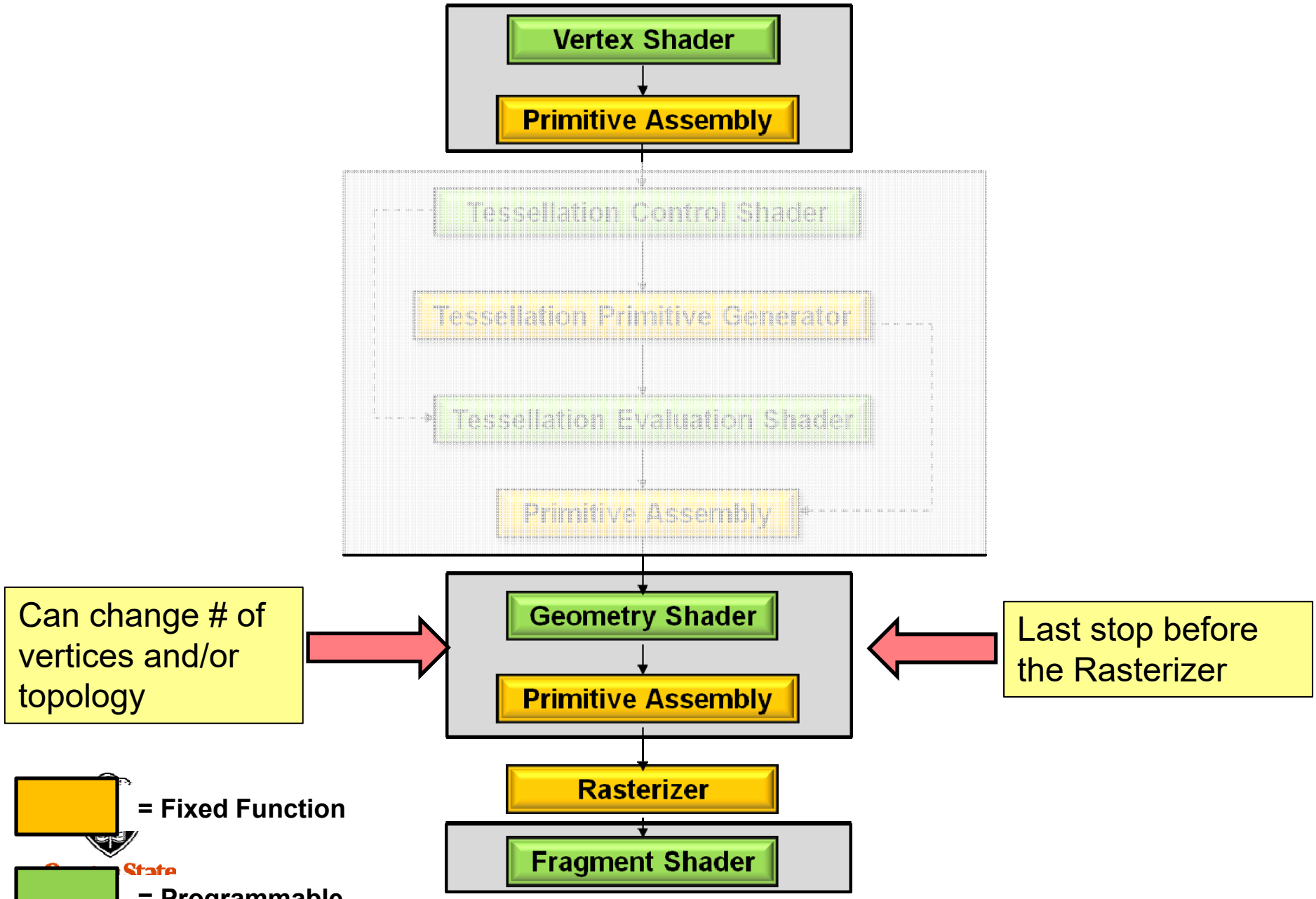
= Fixed Function

= Programmable

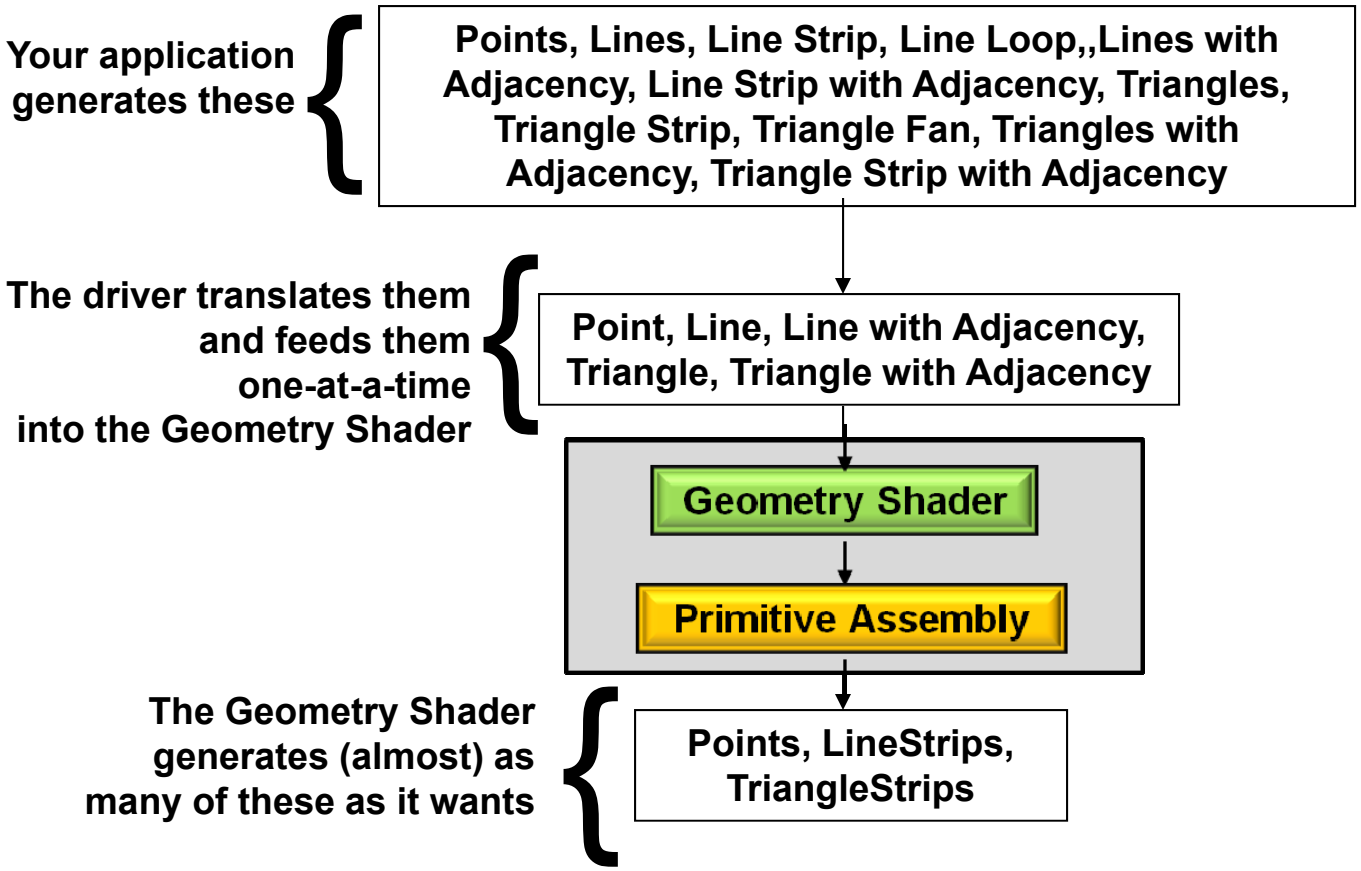
Here's What We Know So Far



The Geometry Shader: Where Does it Fit in the Pipeline?



Geometry Shader: What Does it Do?



There needn't be any correlation between Geometry Shader input type and Geometry Shader output type. Points can generate triangles, triangles can generate triangle strips, etc.

Additional Arguments Available for glBegin( ):

GL_LINES_ADJACENCY

GL_LINE_STRIP_ADJACENCY

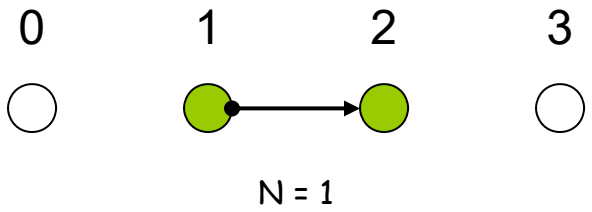
GL_TRIANGLES_ADJACENCY

GL_TRIANGLE_STRIP_ADJECENCY

Adjacency Primitives (and what they do when not using shaders)

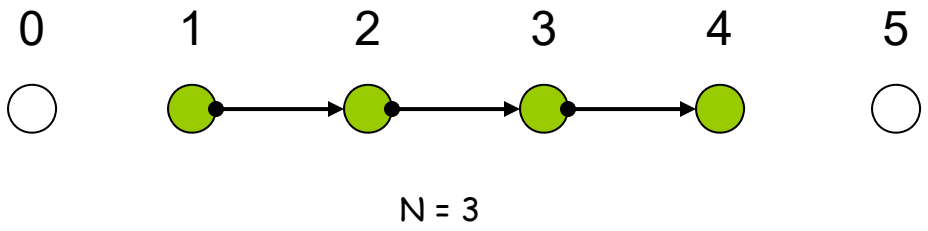
This is what Fixed-Function OpenGL expects these vertices to mean. In Shader World, they can mean whatever you want them to mean. In Shader World, it's just a way to get multiple vertices into a Geometry Shader.

Lines with Adjacency



4N vertices are given.
(where N is the number of line segments to draw).
A line segment is drawn between #1 and #2.
Vertices #0 and #3 are there to provide adjacency information.

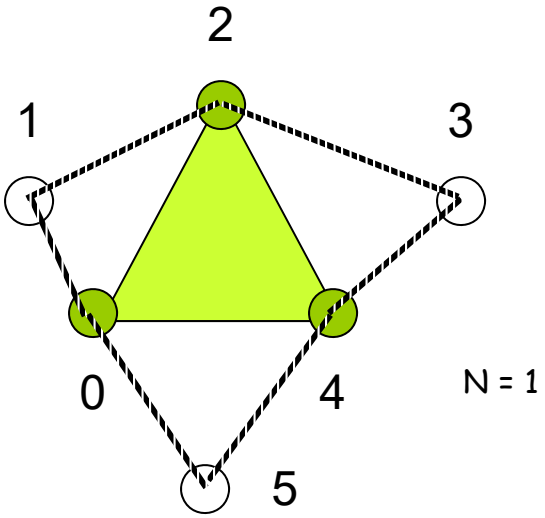
Line Strip with Adjacency



N+3 vertices are given
(where N is the number of line segments to draw).
A line segment is drawn between #1 and #2, #2 and #3, …, #N and #N+1.
Vertices #0 and #N+2 are there to provide adjacency information.

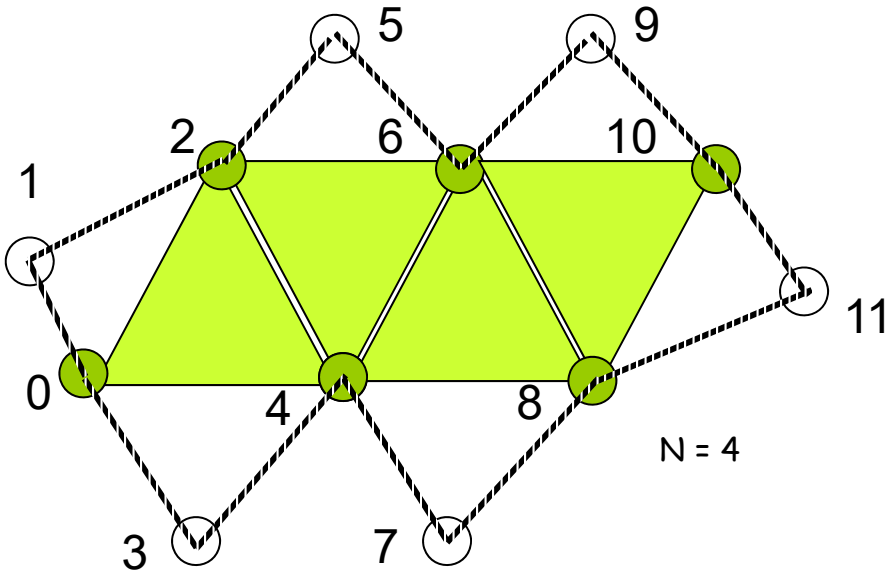
Adjacency Primitives (and what they do when not using shaders)

Triangles with Adjacency



6N vertices are given
(where N is the number of triangles to draw).
Points 0, 2, and 4 define the triangle.
Points 1, 3, and 5 tell where adjacent triangles are.

Triangle Strip with Adjacency



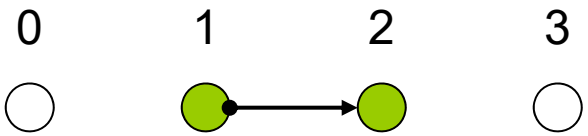
4+2N vertices are given
(where N is the number of triangles to draw).
Points 0, 2, 4, 6, 8, 10, …define the triangles.
Points 1, 3, 5, 7, 9, 11, … tell where adjacent triangles are.

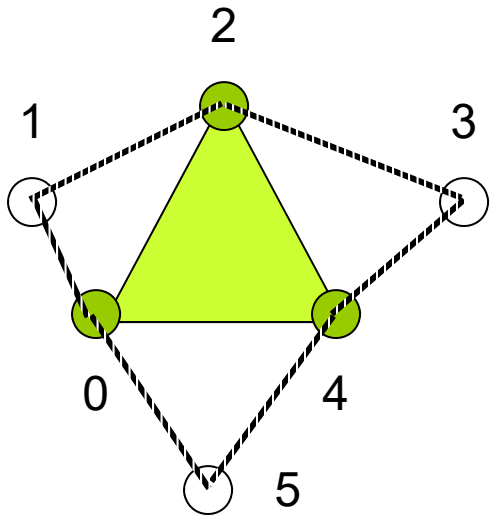
Adjacency Primitives (and what they do when you are using shaders)

In general, we will use the “with adjacency” primitives as a way of importing some number of vertices into the geometry shader.

These are the most useful:

GL_LINES_ADJACENCY	4 vertices
GL_TRIANGLES_ADJACENCY	6 vertices





If a Vertex Shader Writes Variables as:	then the Geometry Shader will Read Them as:	and will Write Them to the Fragment Shader as:
gl_Position	→ gl_PositionIn[▪]	→ gl_Position
gl_PointSize	→ gl_PointSizeIn[▪]	→ gl_PointSize
"out"	*"in"*	*"out"*

In the Geometry Shader, the dimensions indicated by ▪ are given by the variable *gl_VerticesIn*, although you will already know this by the type of geometry you are inputting

1	GL_POINTS
2	GL_LINES
4	GL_LINES_ADJACENCY
3	GL_TRIANGLES
6	GL_TRIANGLES_ADJACENCY

The Geometry Shader Can Assign These Built-in *out* Variables:

gl_Position

gl_PointSize

When the Geometry Shader calls

EmitVertex( )

this set of variables is copied to a slot in the shader's Primitive Assembly step

Plus any of your own variables that you have declared to be *out*

When the Geometry Shader calls

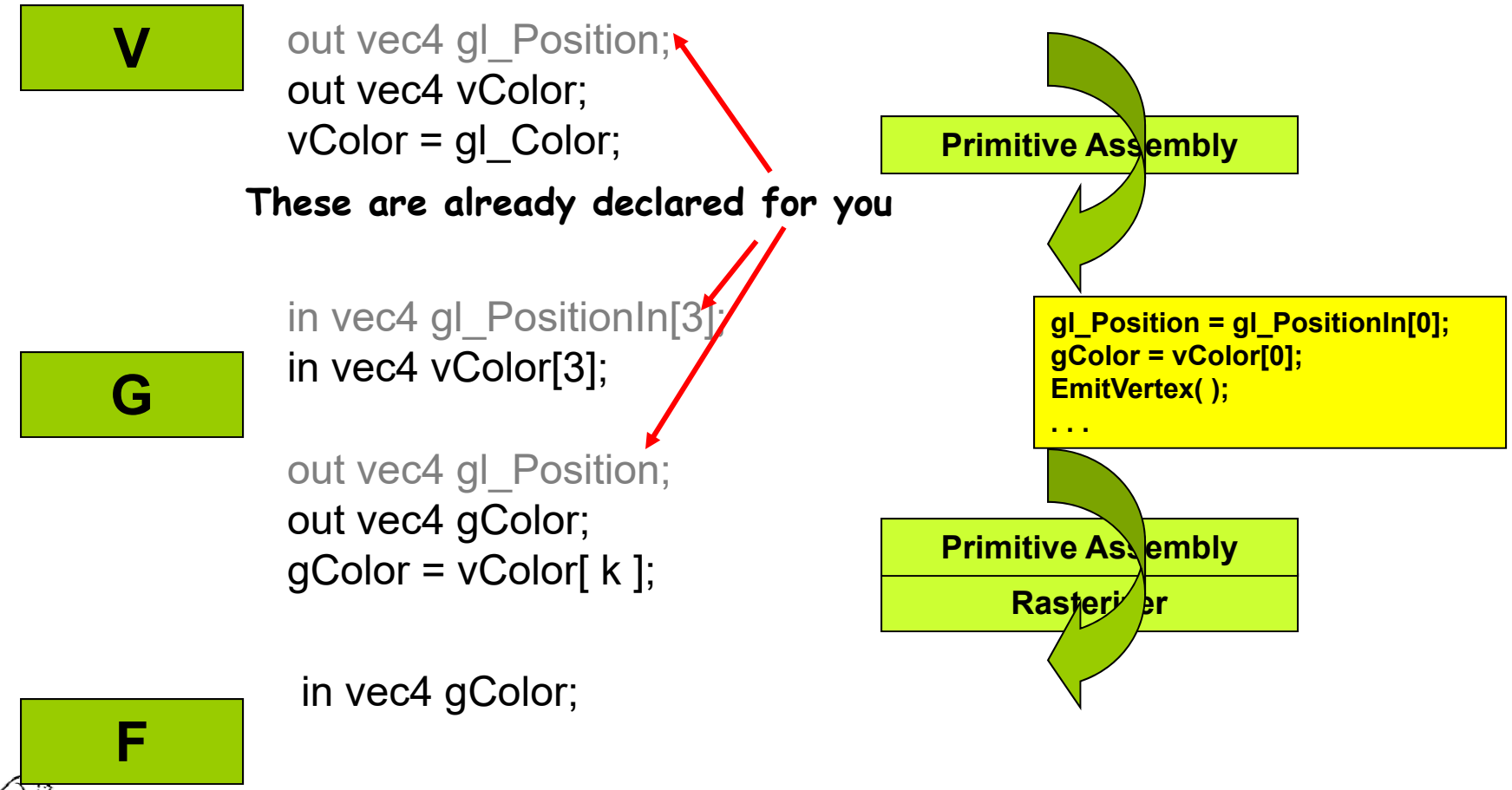
EndPrimitive( )

the vertices that have been saved in the Primitive Assembly step are then assembled, rasterized, etc.

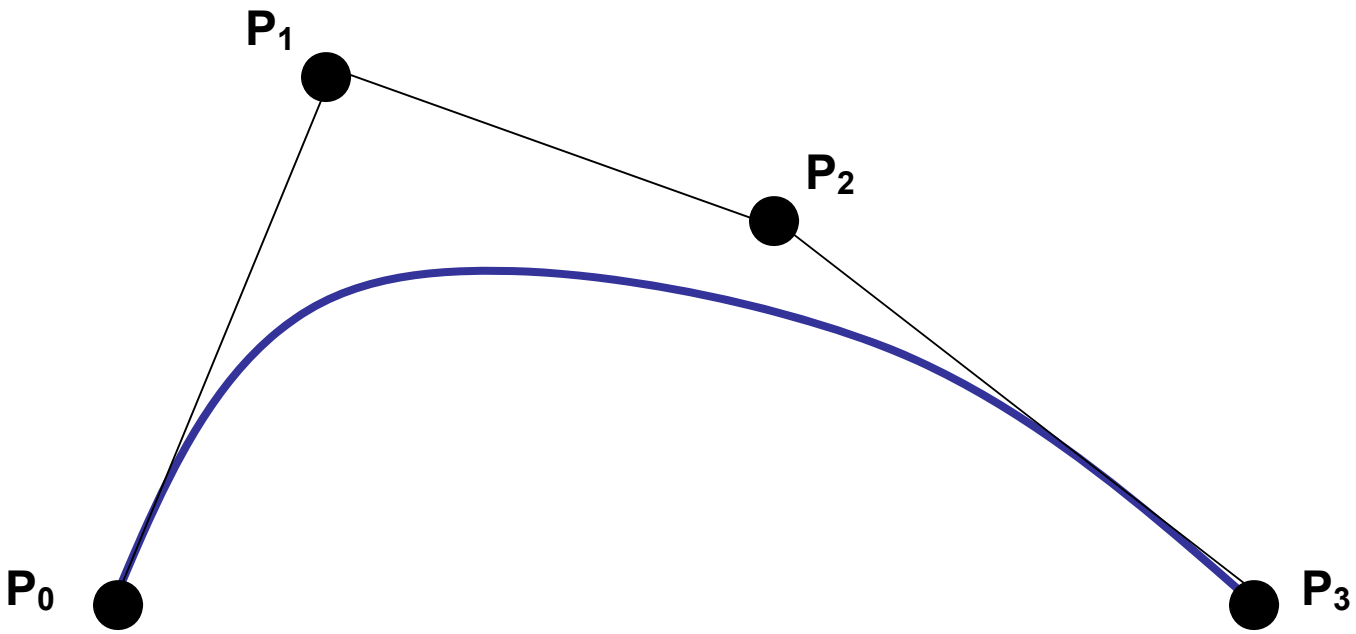
Note: there is no "BeginPrimitive( )" function. It is implied by (1) the start of the Geometry Shader, or (2) returning from the EndPrimitive( ) call.

Note: there is no need to call EndPrimitive( ) at the end of the Geometry Shader – it is implied.

If you are using a Geometry Shader, then the GS must be used if you want to pass information from the Vertex Shader to the Fragment Shader



Example: A Bézier Curve



$$P(u) = (1-u)^3 P_0 + 3u(1-u)^2 P_1 + 3u^2(1-u)P_2 + u^3 P_3$$

Need to pass 4 points in to define the curve. Need to pass N points out to draw the curve.

Example: Expanding 4 Points into a Bezier Curve with a Variable Number of Line Segments

beziercurve.glib

```
Vertex      beziercurve.vert
Geometry beziercurve.geom
Fragment beziercurve.frag
Program  BezierCurve  uNum <2 4 50>

LineWidth 3.
LinesAdjacency [0. 0. 0.]  [1. 1. 1.]  [2. 1. 2.]  [3. -1. 0.]
```

beziercurve.vert

```
void main( )
{
        gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

beziercurve.frag

```
void main( )
{
   gl_FragColor = vec4( 0., 1., 0., 1. );
}
```

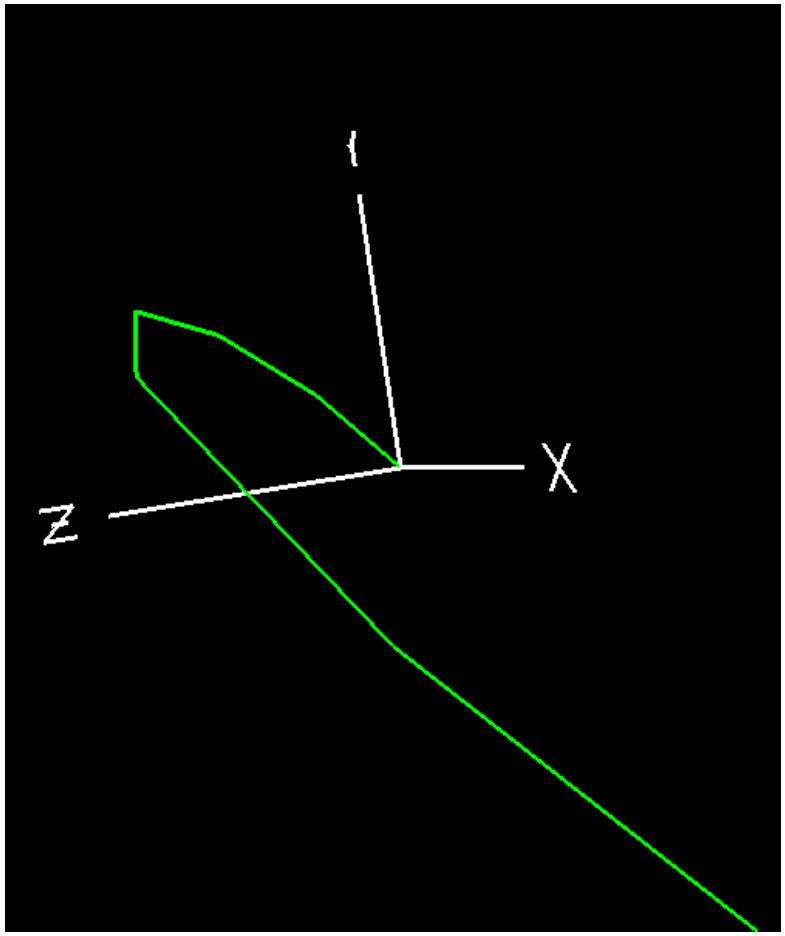
Example: Expanding 4 Points into a Bezier Curve with a Variable Number of Line Segments

beziercurve.geom

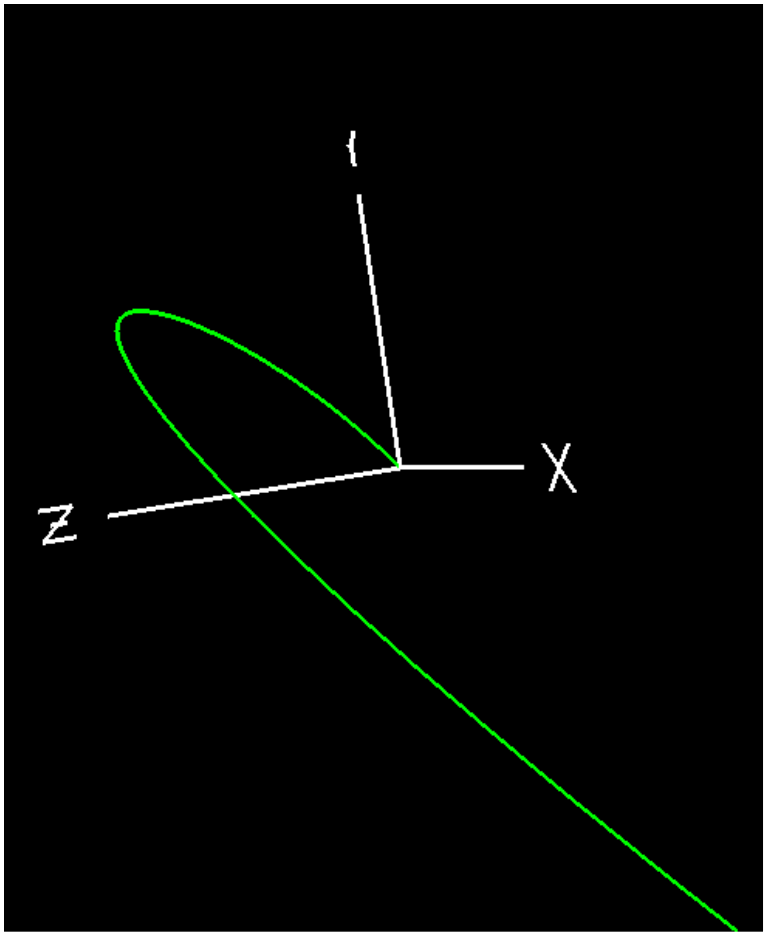
```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( lines_adjacency )  in;
layout( line_strip, max_vertices=200 )  out;
uniform int uNum;
void
main( )
{
        float dt = 1. / float(uNum);
        float t = 0.;
        for( int i = 0; i <= uNum; i++ )
        {
                float omt = 1. - t;
                float omt2 = omt * omt;
                float omt3 = omt * omt2;
                float t2 = t * t;
                float t3 = t * t2;
                vec4 xyzw =                    omt3 * gl_PositionIn[0].xyzw  +
                                          3. * t * omt2 * gl_PositionIn[1].xyzw  +
                                          3. * t2 * omt * gl_PositionIn[2].xyzw  +
                                                t3 * gl_PositionIn[3].xyzw;

                gl_Position = xyzw;
                EmitVertex( )
                t += dt;
        }
}
```

Note: these are used to define the storage

Example: Expanding 4 Points into a Bezier Curve with a Variable Number of Line Segments



uNum = 5



uNum = 25

Note: It would have made no Difference if the Matrix Transform had been done in the Geometry Shader Instead

beziercurve.vert

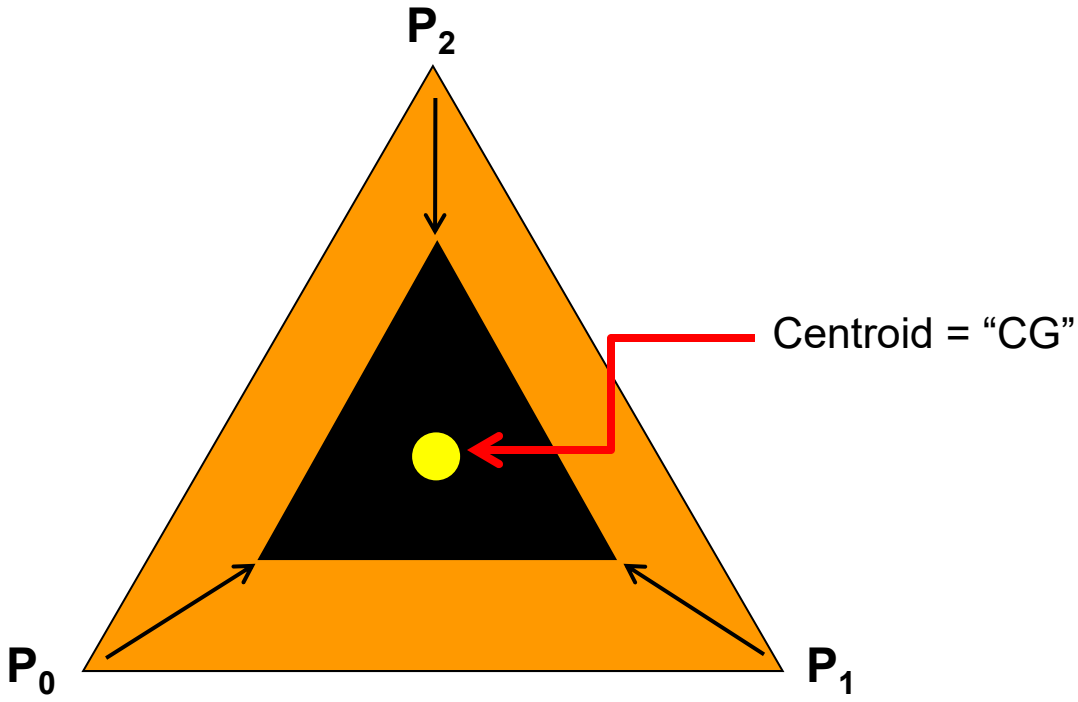
```
void
main( )
{
        gl_Position = gl_Vertex;
}
```

beziercurve.geom

```
. . .
                vec4 xyzw =          omt3 * gl_PositionIn[0].xyzw  +
                                  3. * t * omt2 * gl_PositionIn[1].xyzw  +
                                  3. * t2 * omt * gl_PositionIn[2].xyzw  +
                                        t3 * gl_PositionIn[3].xyzw;

                gl_Position = gl_ModelViewProjectionMatrix * xyzw;
                EmitVertex( )
                t += dt;
        }
```

Another Example: Shrinking Triangles

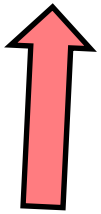
Example: Shrinking Triangles



$$CG = (P_0 + P_1 + P_2) / 3.;$$
$$P_0' = CG + uShrink * (P_0 - CG)$$
$$P_1' = CG + uShrink * (P_1 - CG)$$
$$P_2' = CG + uShrink * (P_2 - CG)$$

shrink.geom

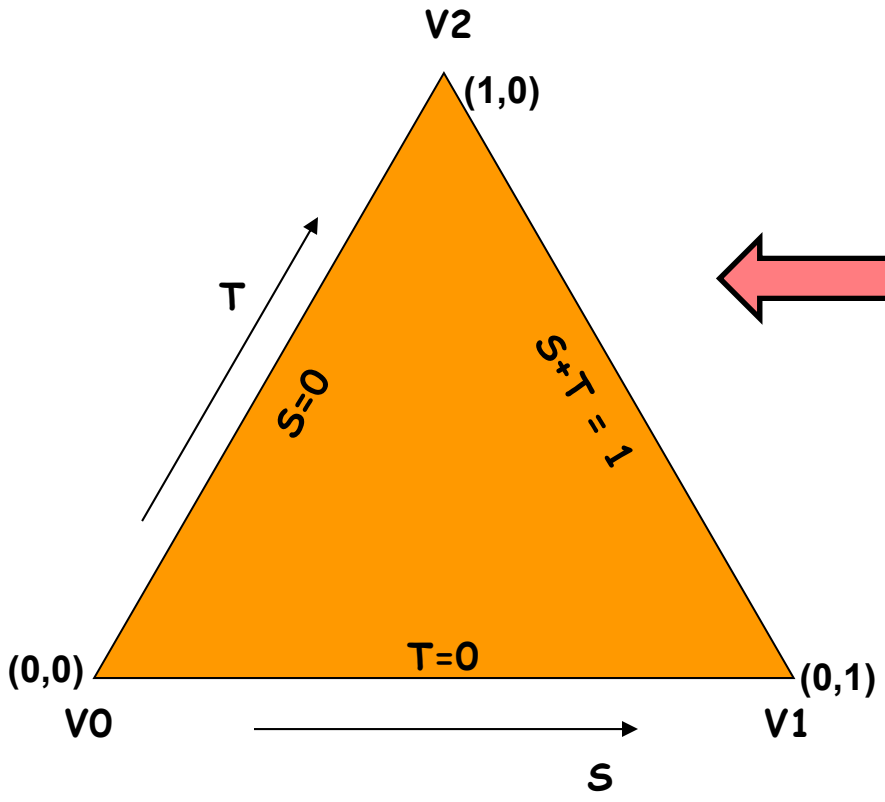
```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( triangles )  in;
layout( triangle_strip, max_vertices=200 )  out;

uniform float       uShrink;
in vec3    vNormal[3];
out float  gLightIntensity;
const vec3 LIGHTPOS = vec3( 0., 10., 0. );
vec3 V[3];
vec3 CG;

void
ProduceVertex( int v )
{
      g LightIntensity  = dot( normalize(LIGHTPOS- V[v]), vNormal[v] );
      g LightIntensity = abs( gLightIntensity );

       gl_Position = gl_ModelViewProjectionMatrix * vec4( CG + uShrink * ( V[v] - CG ), 1. );
       EmitVertex( );
}

void
main( )
{
       V[0]  =   gl_PositionIn[0].xyz;
       V[1]  =   gl_PositionIn[1].xyz;
       V[2]  =   gl_PositionIn[2].xyz;
       CG = (  V[0] + V[1] + V[2]  ) / 3.;
       ProduceVertex( 0 );
       ProduceVertex( 1 );
       ProduceVertex( 2 );
}
```



$$CG = (P_0 + P_1 + P_2) / 3.;$$
$$P_0' = CG + uShrink * (P_0 - CG)$$
$$P_1' = CG + uShrink * (P_1 - CG)$$
$$P_2' = CG + uShrink * (P_2 - CG)$$

Another Example: Sphere Subdivision

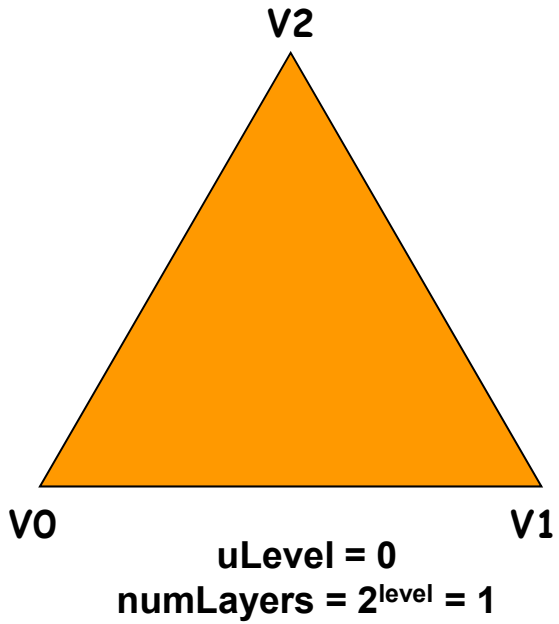
It's often useful to be able to parameterize a triangle into (s,t), like this:



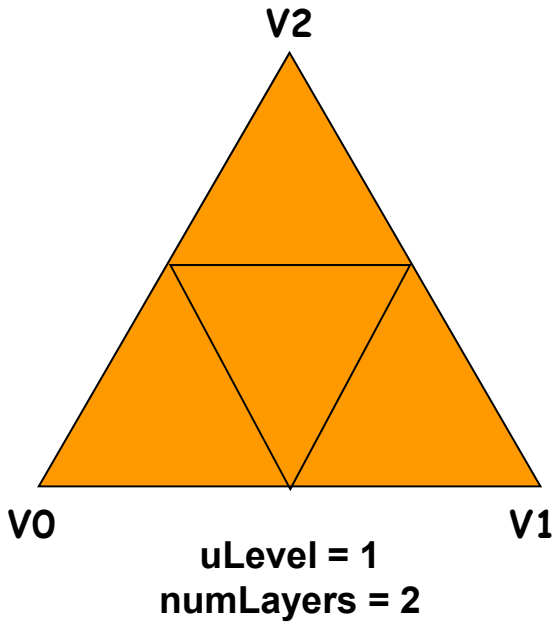
Note! There is no place in this triangle where S = T = 1.

v(s,t) = V0 + s*(V1-V0) + t*(V2-V0)

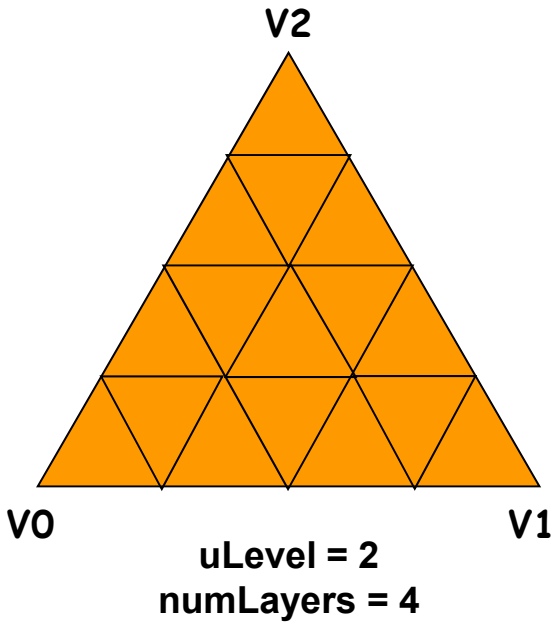
Example: Sphere Subdivision



uLevel = 0
numLayers = 2^{level} = 1



uLevel = 1
numLayers = 2



uLevel = 2
numLayers = 4

Example: Sphere Subdivision

spheresubd.glib

```
Vertex      spheresubd.vert
Geometry spheresubd.geom
Fragment spheresubd.frag
Program  SphereSubd  uLevel <0 0 10>  uRadius <.5 1. 5.>  uColor { 1. .5 .15 1. }


Triangles [ 0. 0.  1.]  [ 1. 0.  0.]  [0.  1. 0.]
Triangles [ 1. 0.  0.]  [ 0. 0. -1.]  [0.  1. 0.]
Triangles [ 0. 0. -1.]  [-1. 0.  0.]  [0.  1. 0.]
Triangles [-1. 0.  0.]  [ 0. 0.  1.]  [0.  1. 0.]

Triangles [ 0. 0.  1.]  [ 1. 0.  0.]  [0. -1. 0.]
Triangles [ 1. 0.  0.]  [ 0. 0. -1.]  [0. -1. 0.]
Triangles [ 0. 0. -1.]  [-1. 0.  0.]  [0. -1. 0.]
Triangles [-1. 0.  0.]  [ 0. 0.  1.]  [0. -1. 0.]
```

Example: Sphere Subdivision

spheresubd.vert

```
void
main( )
{
        gl_Position = gl_Vertex;
}
```

spheresubd.frag

```
uniform vec4 uColor;
in float     gLightIntensity;

void
main( )
{
        gl_FragColor = vec4(  gLightIntensity*uColor.rgb, 1. );
}
```

Example: Sphere Subdivision

spheresubd.geom

```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( triangles )  in;
layout( triangle_strip, max_vertices=200 )  out;

uniform int    uLevel;
uniform float uRadius;
out  float       gLightIntensity;
const vec3 LIGHTPOS = vec3( 0., 10., 0. );

vec3 V0, V01, V02;

void
ProduceVertex( float s, float t )
{
        vec3 v = V0 + s*V01 + t*V02;
        v = normalize(v);
        vec3 n = v;
        vec3 tnorm = normalize( gl_NormalMatrix * n );  // the transformed normal

        vec4 ECposition = gl_ModelViewMatrix * vec4( (uRadius*v), 1. );
        gLightIntensity  = abs(   dot( normalize(LIGHTPOS - ECposition.xyz), tnorm )   );

        gl_Position = gl_ProjectionMatrix * ECposition;
        EmitVertex( );
}
```

Example: Sphere Subdivision

spheresubd.geom

```
void
main( )
{
	V01 = ( gl_PositionIn[1] - gl_PositionIn[0] ).xyz;
	V02 = ( gl_PositionIn[2] - gl_PositionIn[0] ).xyz;
	V0  =   gl_PositionIn[0].xyz;

	int numLayers = 1 << uLevel;

	float dt = 1. / float( numLayers );

	float t_top = 1.;

	for( int it = 0; it < numLayers; it++ )
	{
		. . .
```

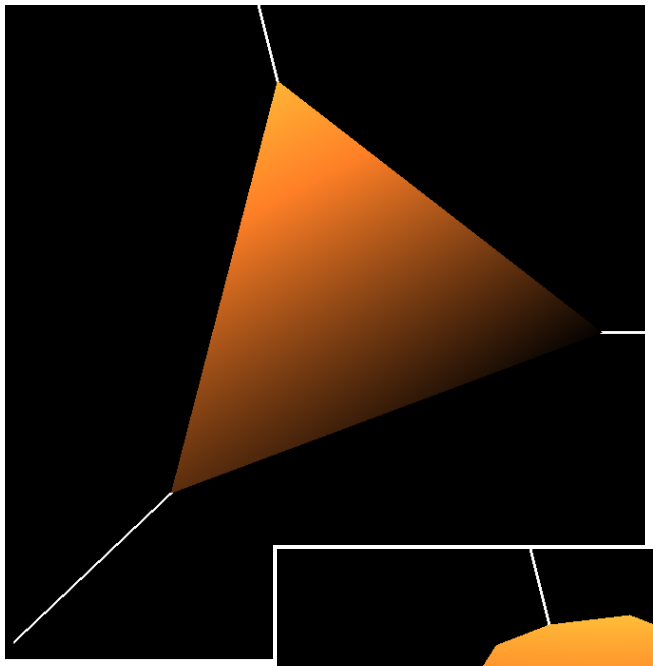
Example: Sphere Subdivision

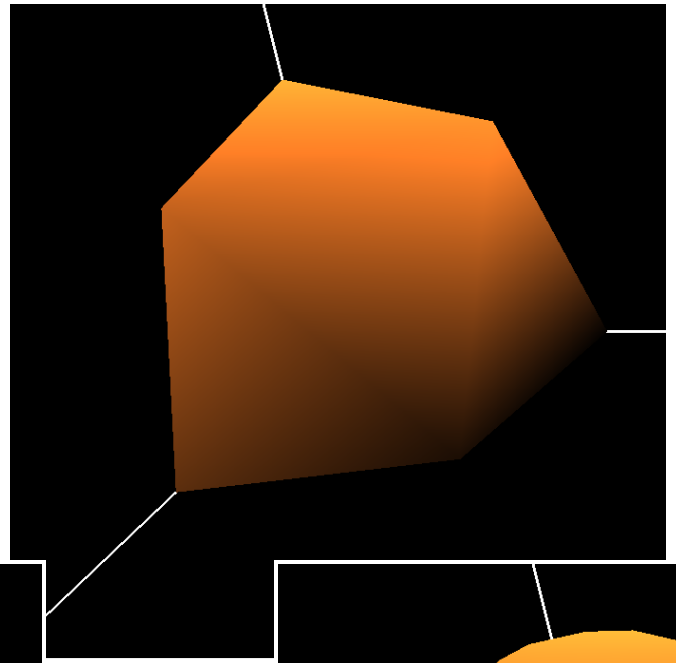
spheresubd.geom

```
	for( int it = 0; it < numLayers; it++ )
	{
		float t_bot = t_top - dt;
		float smax_top = 1. - t_top;
		float smax_bot = 1. - t_bot;

		int nums = it + 1;
		float ds_top = smax_top / float( nums - 1 );
		float ds_bot = smax_bot / float( nums );

		float s_top = 0.;
		float s_bot = 0.;

		for( int is = 0; is < nums; is++ )
		{
			ProduceVertex( s_bot, t_bot );
			ProduceVertex( s_top, t_top );
			s_top += ds_top;
			s_bot += ds_bot;
		}

		ProduceVertex( s_bot, t_bot );
		EndPrimitive( );

		t_top = t_bot;
		t_bot -= dt;
	}
}
```

Example: Sphere Subdivision with One triangle

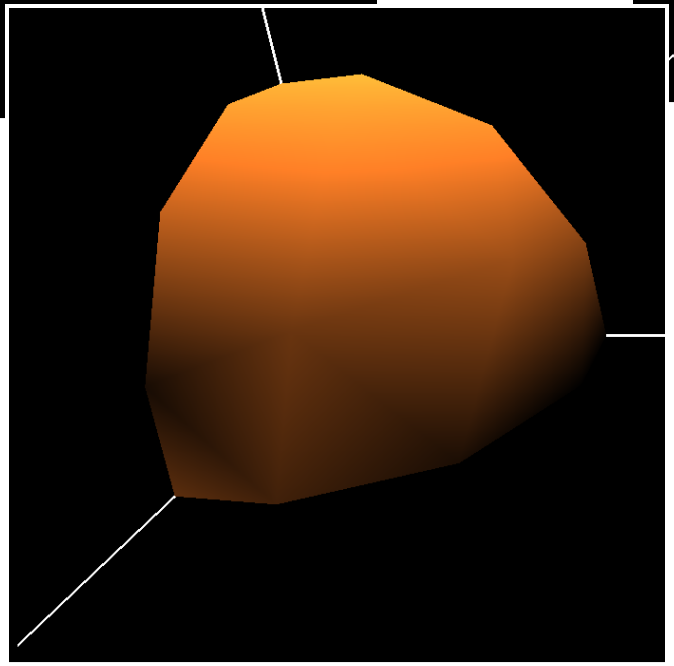
Level = 0



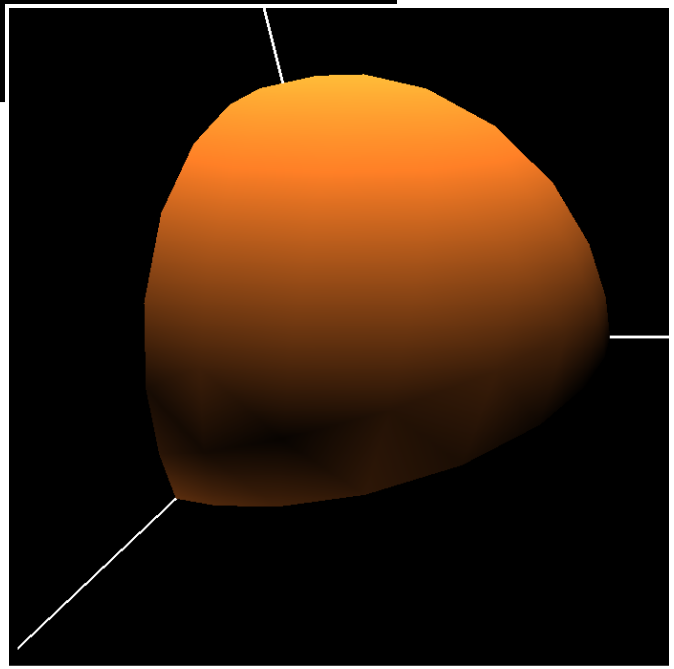


Level = 1

Level = 2

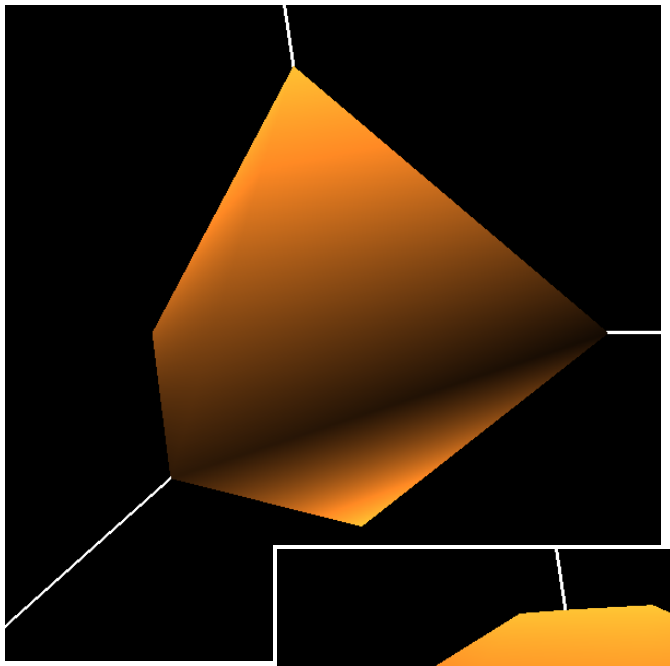


Level = 3

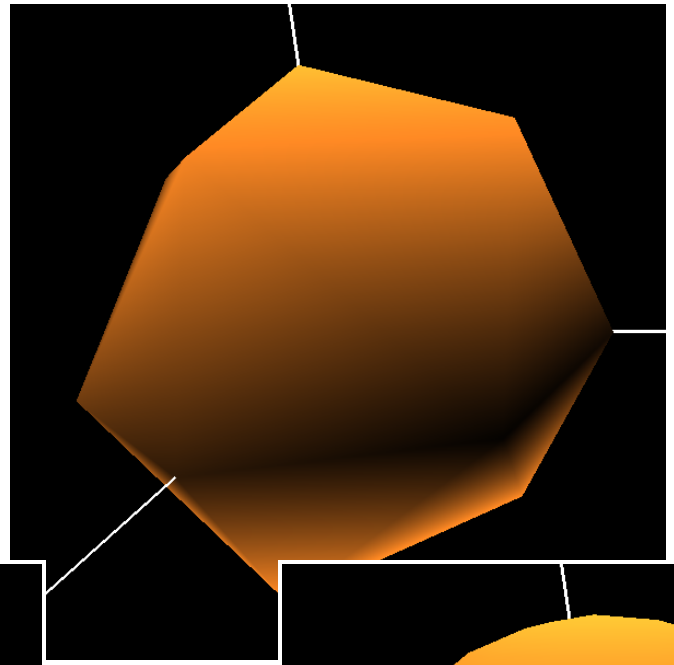


Example: Sphere Subdivision with the Whole Sphere (8 triangles)

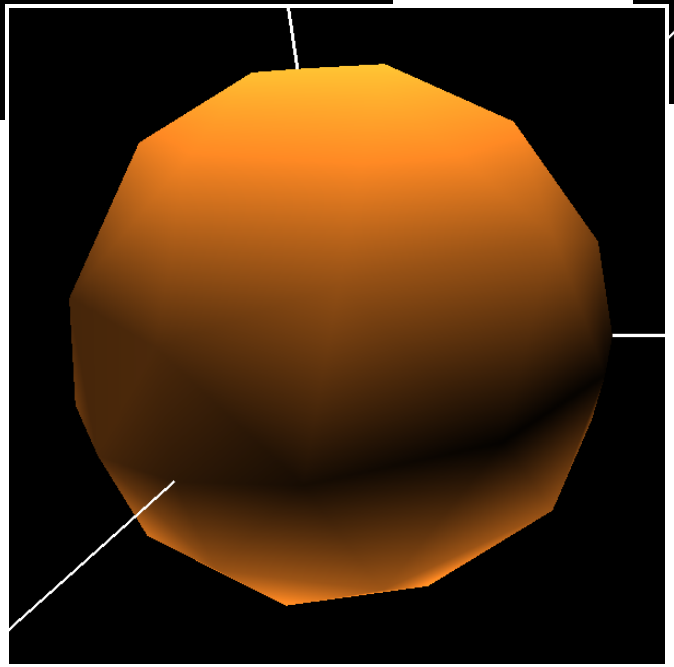
Level = 0



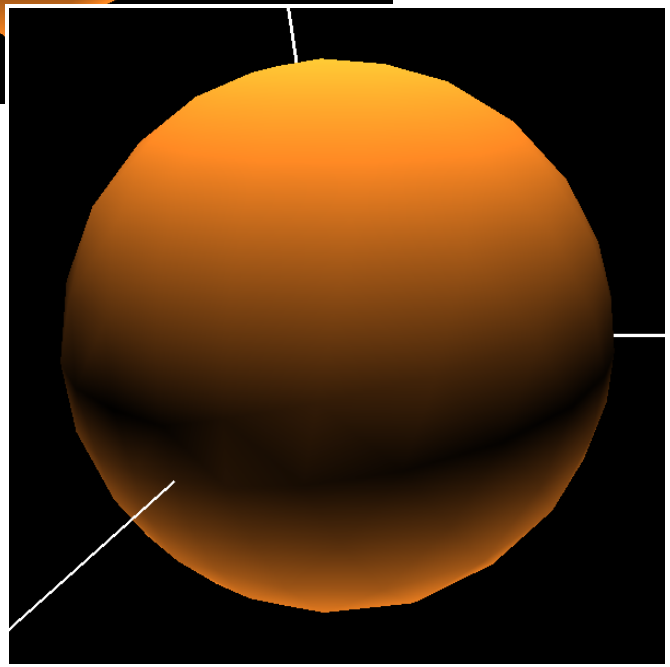
Level = 1



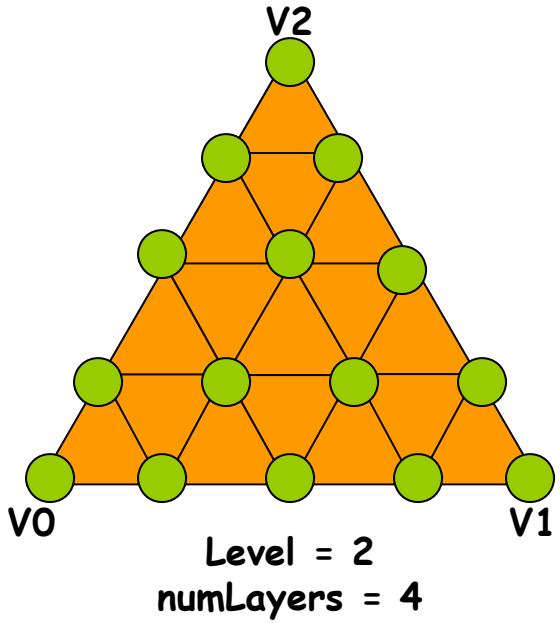
Level = 2

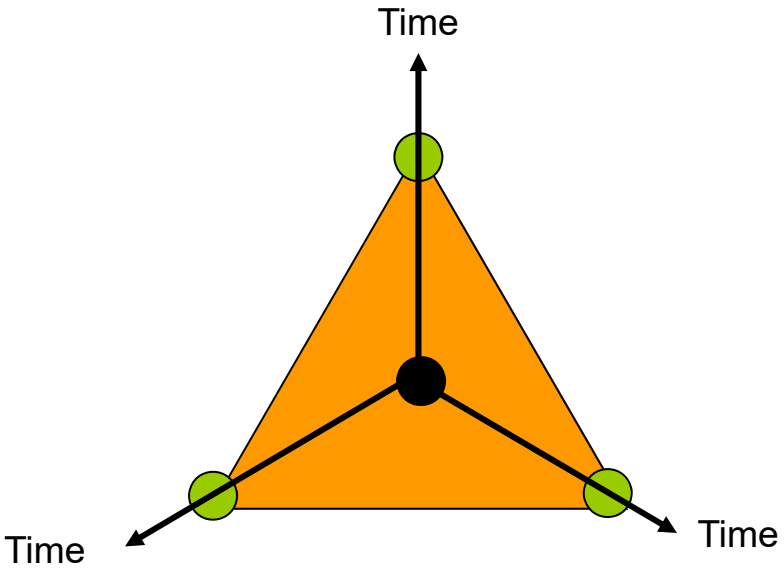


Level = 3



Another Example: Explosion





1. Break the triangles into points
2. Treat each point's distance from the triangle's CG as an initial velocity
3. Follow the laws of projectile motion:

$$x = x_0 + v_x t$$

$$y = y_0 + v_y t + \frac{1}{2} a_y t^2$$

Example: Explosion

explode.geom

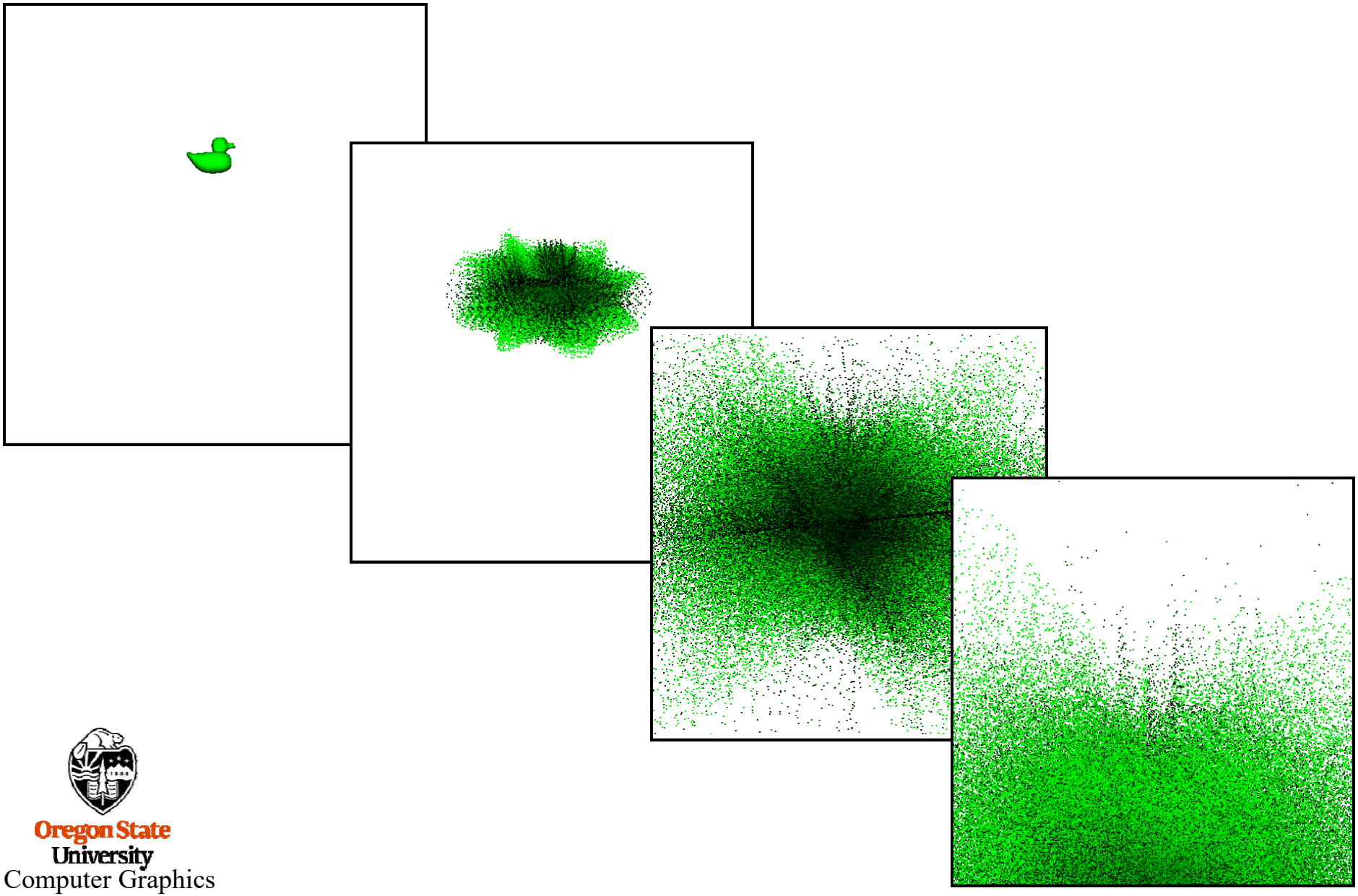
```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( triangles )  in;
layout( points, max_vertices=200 )  out;

uniform int    uLevel;
uniform float uGravity;
uniform float uTime;
uniform float uVelScale;

vec3    V0, V01, V02;
vec3    CG;

void
ProduceVertex( float s, float t )
{
        vec3 v = V0 + s*V01 + t*V02;
        vec3 vel = uVelScale * ( v - CG );
        v = CG + vel*uTime + 0.5*vec3(0.,uGravity,0.)*uTime*uTime;
        gl_Position = gl_ProjectionMatrix * vec4( v, 1. );
        EmitVertex( );
}
```

explode.geom

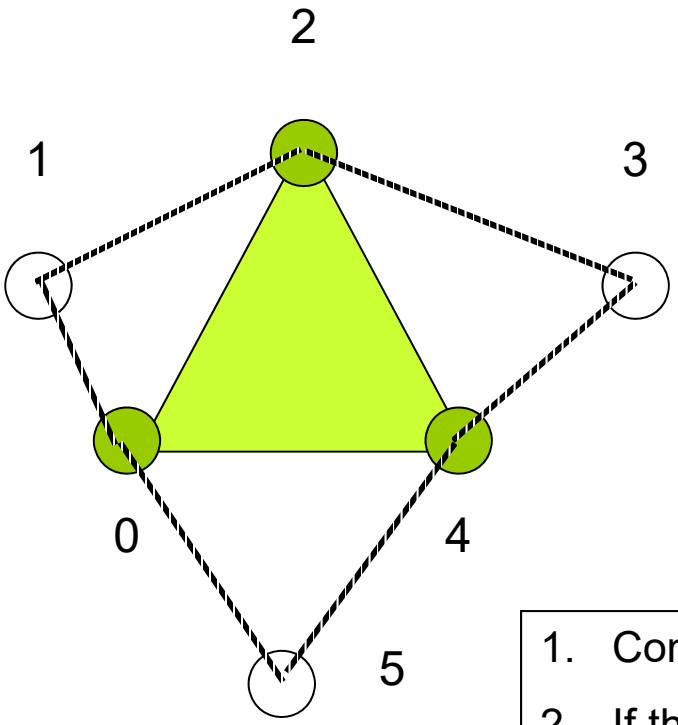
Example: Explosion

```
void
main( )
{
	V01 = ( gl_PositionIn[1] - gl_PositionIn[0] ).xyz;
	V02 = ( gl_PositionIn[2] - gl_PositionIn[0] ).xyz;
	V0  =   gl_PositionIn[0].xyz;
	CG = ( gl_PositionIn[0].xyz + gl_PositionIn[1].xyz + gl_PositionIn[2].xyz ) / 3.;

	int numLayers = 1 << uLevel;

	float dt = 1. / float( numLayers );
	float t = 1.;

	for( int it = 0; it <= numLayers; it++ )
	{
		float smax = 1. - t;
		int nums = it + 1;
		float ds = smax / float( nums - 1 );
		float s = 0.;

		for( int is = 0; is < nums; is++ )
		{
			ProduceVertex( s, t );
			s += ds;
		}

		t -= dt;
	}
}
```

Example: Explosion



Another Example: Silhouettes



1. Compute the normals of each of the four triangles
2. If there is a sign difference between the z component of the center triangle's normal and the z component of an adjacent triangle's normal, draw their common edge

   I.e., you are looking for a *crease*.

Example: Silhouettes

silh.glib

```
Obj bunny.obj

Vertex      silh.vert
Geometry silh.geom
Fragment silh.frag
Program  Silhouette  uColor { 0. 1. 0. 1. }

ObjAdj   bunny.obj
```

Example: Silhouettes

silh.vert

```
void
main( )
{
        gl_Position = gl_ModelViewMatrix * gl_Vertex;
}
```

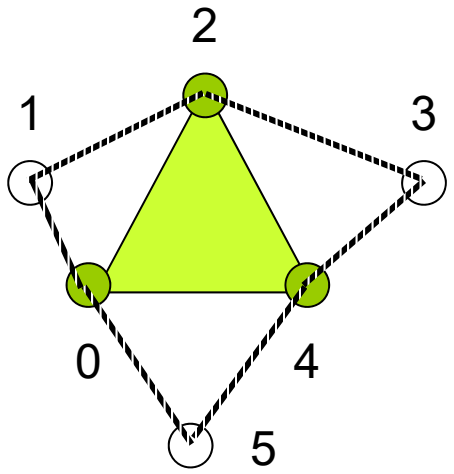
silh.frag

```
uniform vec4 uColor;

void
main( )
{
        gl_FragColor = vec4( uColor.rgb, 1. );
}
```

Example: Silhouettes

silh.geom

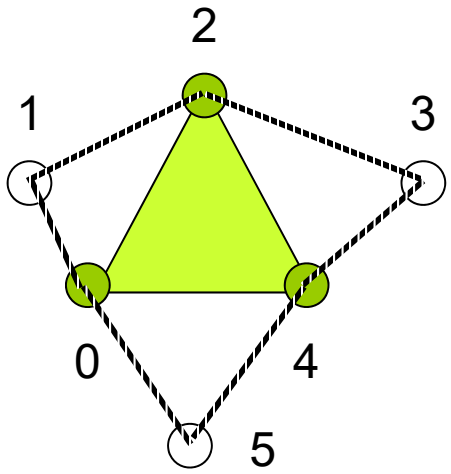
```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( triangles_adjacency )  in;
layout( line_strip, max_vertices=200 )  out;
void main( )
{
        vec3 V0 = gl_PositionIn[0].xyz;
        vec3 V1 = gl_PositionIn[1].xyz;
        vec3 V2 = gl_PositionIn[2].xyz;
        vec3 V3 = gl_PositionIn[3].xyz;
        vec3 V4 = gl_PositionIn[4].xyz;
        vec3 V5 = gl_PositionIn[5].xyz;

        vec3 N042 = cross( V4-V0, V2-V0 );          // the center triangle's normal
        vec3 N021 = cross( V2-V0, V1-V0 );
        vec3 N243 = cross( V4-V2, V3-V2 );
        vec3 N405 = cross( V0-V4, V5-V4 );

        if( dot( N042, N021 ) < 0. )                // make sure each outer triangle's
                N021 = vec3(0.,0.,0.) - N021;       // normal is in the same general direction

        if( dot( N042, N243 ) < 0. )
                N243 = vec3(0.,0.,0.) - N243;

        if( dot( N042, N405 ) < 0. )
                N405 = vec3(0.,0.,0.) - N405;
```



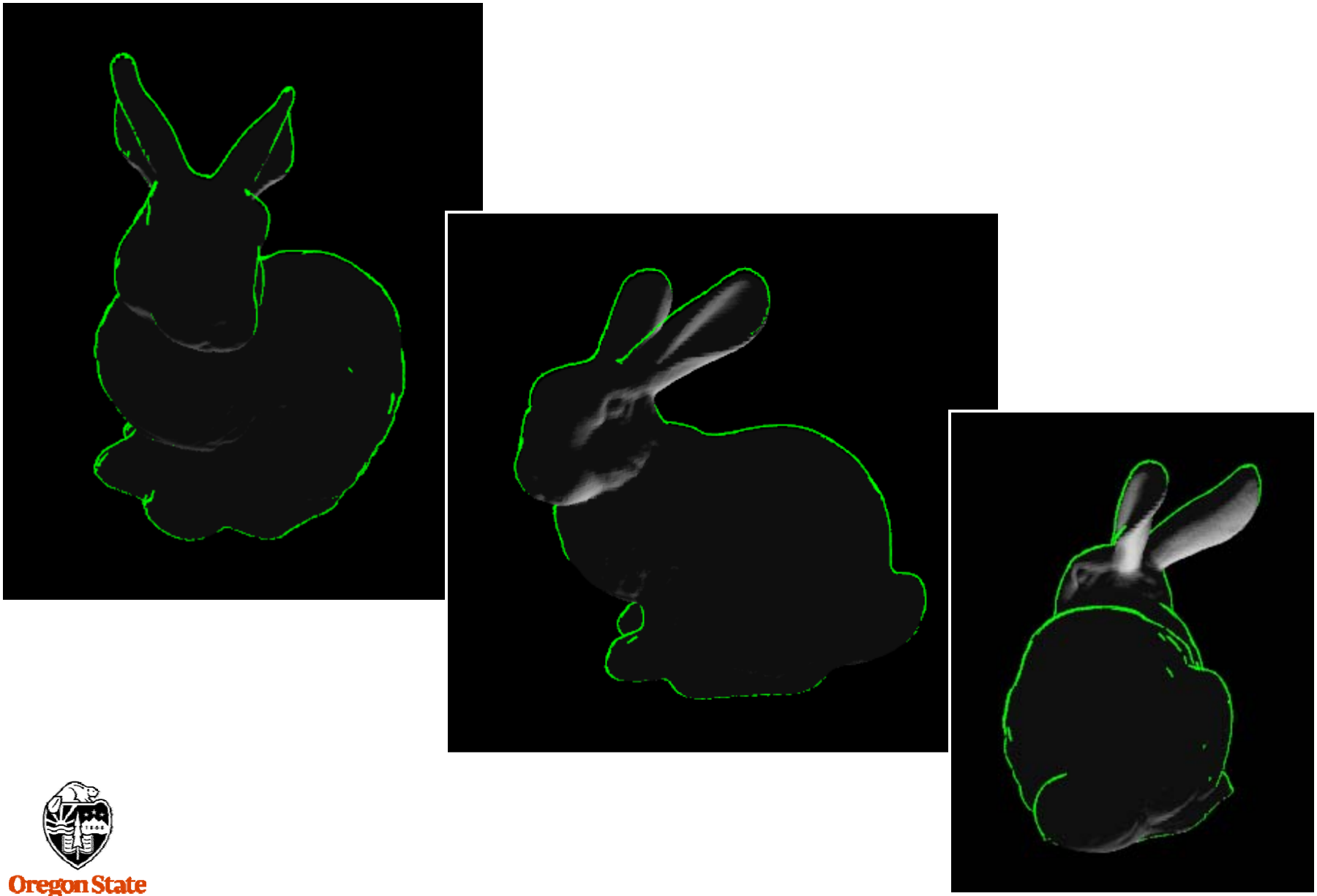
silh.geom

Example: Silhouettes

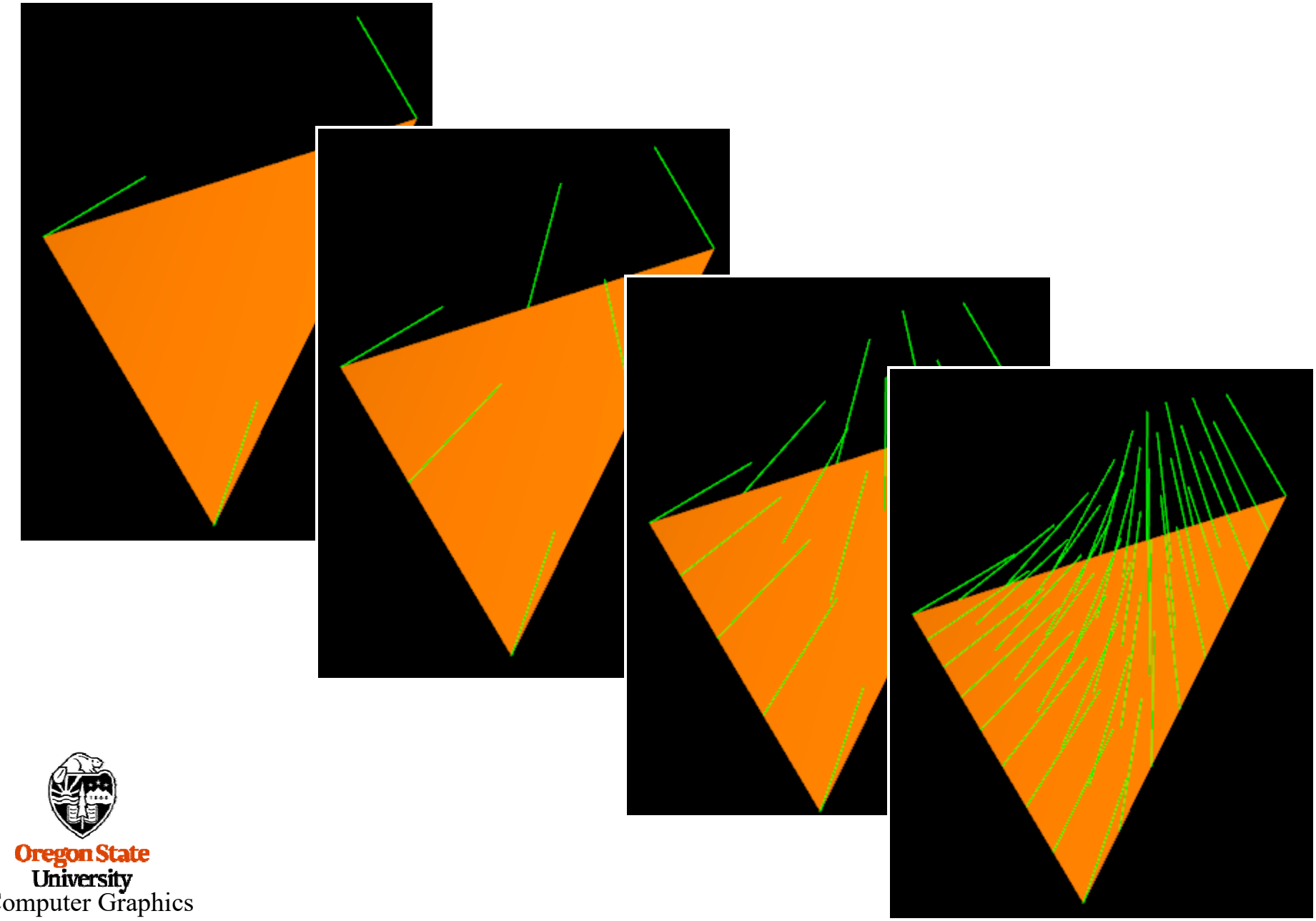
```
        if( N042.z * N021.z <= 0. )
        {
                gl_Position = gl_ProjectionMatrix * vec4( V0, 1. );
                EmitVertex( );
                gl_Position = gl_ProjectionMatrix * vec4( V2, 1. );
                EmitVertex( );
                EndPrimitive( );
        }

        if( N042.z * N243.z <= 0. )
        {
                gl_Position = gl_ProjectionMatrix * vec4( V2, 1. );
                EmitVertex( );
                gl_Position = gl_ProjectionMatrix * vec4( V4, 1. );
                EmitVertex( );
                EndPrimitive( );
        }

        if( N042.z * N405.z <= 0. )
        {
                gl_Position = gl_ProjectionMatrix * vec4( V4, 1. );
                EmitVertex( );
                gl_Position = gl_ProjectionMatrix * vec4( V0, 1. );
                EmitVertex( );
                EndPrimitive( );
        }
}
```



Example: Bunny Silhouettes



Another Example: Hedgehog Plots



hedgehog.geom, I

```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( triangles )  in;
layout( line_strip, max_vertices=200 )  out;

uniform int    uDetail;
uniform float  uDroop;
uniform int    uLength;
uniform float  uStep;
in vec3   vTnorm[3];
in vec4   vColor[3];
out vec4  gColor;

int lLength;
vec3 Norm[3];
vec3 N0, N01, N02;
vec4 V0, V01, V02;

void
ProduceVertices( float s, float t )
{
	vec4 v = V0 + s*V01 + t*V02;
	vec3 n = normalize( N0 + s*N01 + t*N02 );

	for( int i = 0; i <= uLength; i++ )
	{
		gl_Position = gl_ProjectionMatrix * v;
		gColor = vColor[0];
		EmitVertex( );
		v.xyz += uStep * n;
		v.y -= uDroop * float(i*i);
	}
	EndPrimitive( );
}
```

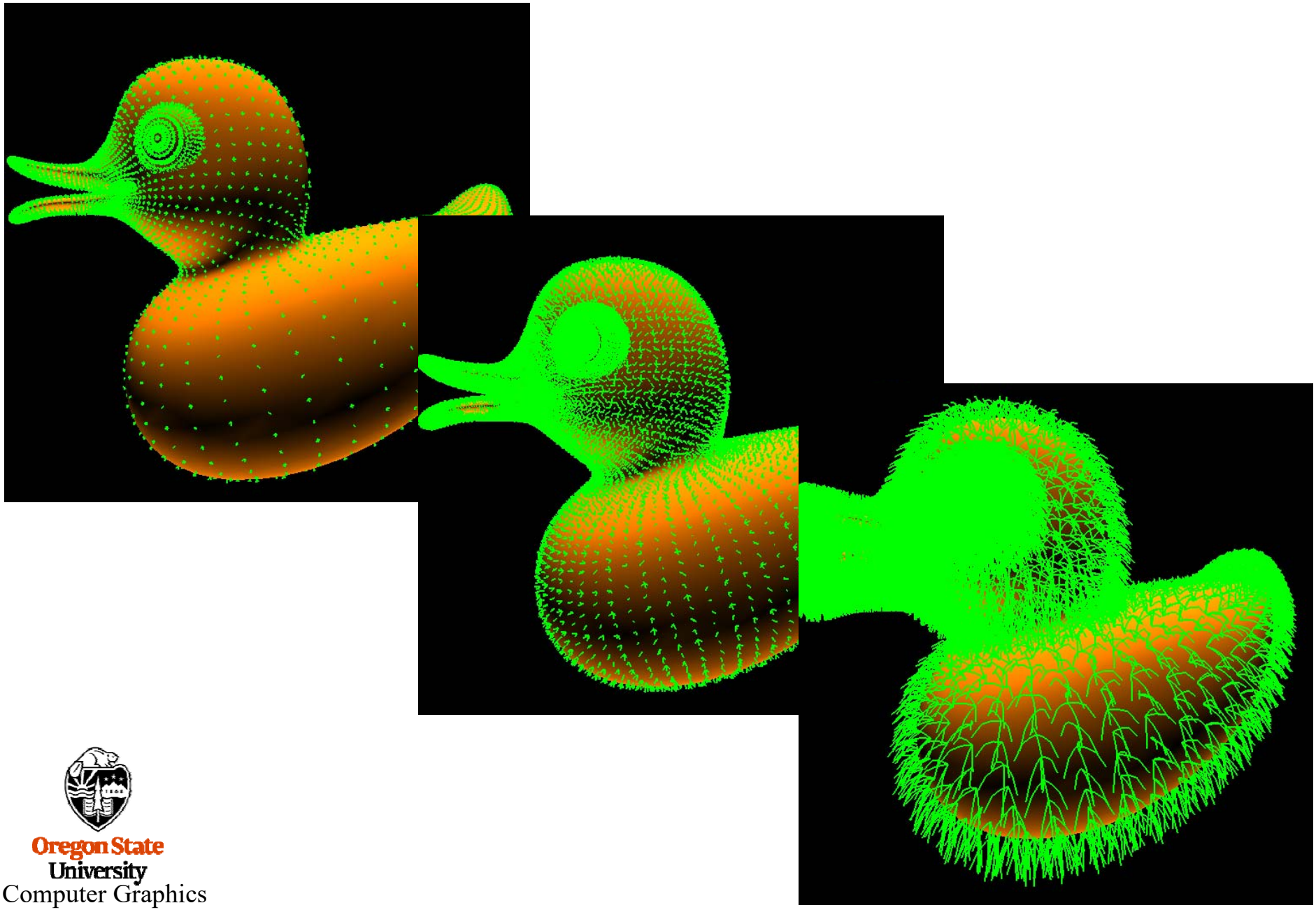
hedgehog.geom, II

```
void
main( )
{
	V0  =   gl_PositionIn[0];
	V01 = ( gl_PositionIn[1] - gl_PositionIn[0] );
	V02 = ( gl_PositionIn[2] - gl_PositionIn[0] );
	Norm[0] = vTnorm[0];
	Norm[1] = vTnorm[1];
	Norm[2] = vTnorm[2];

	if( dot( Norm[0], Norm[1] ) < 0. )
		Norm[1] = -Norm[1];
	if( dot( Norm[0], Norm[2] ) < 0. )
		Norm[2] = -Norm[2];

	N0   = normalize( Norm[0] );
	N01 = normalize( Norm[1] - Norm[0] );
	N02 = normalize( Norm[2] - Norm[0] );

	int numLayers = 1 << uDetail;
```

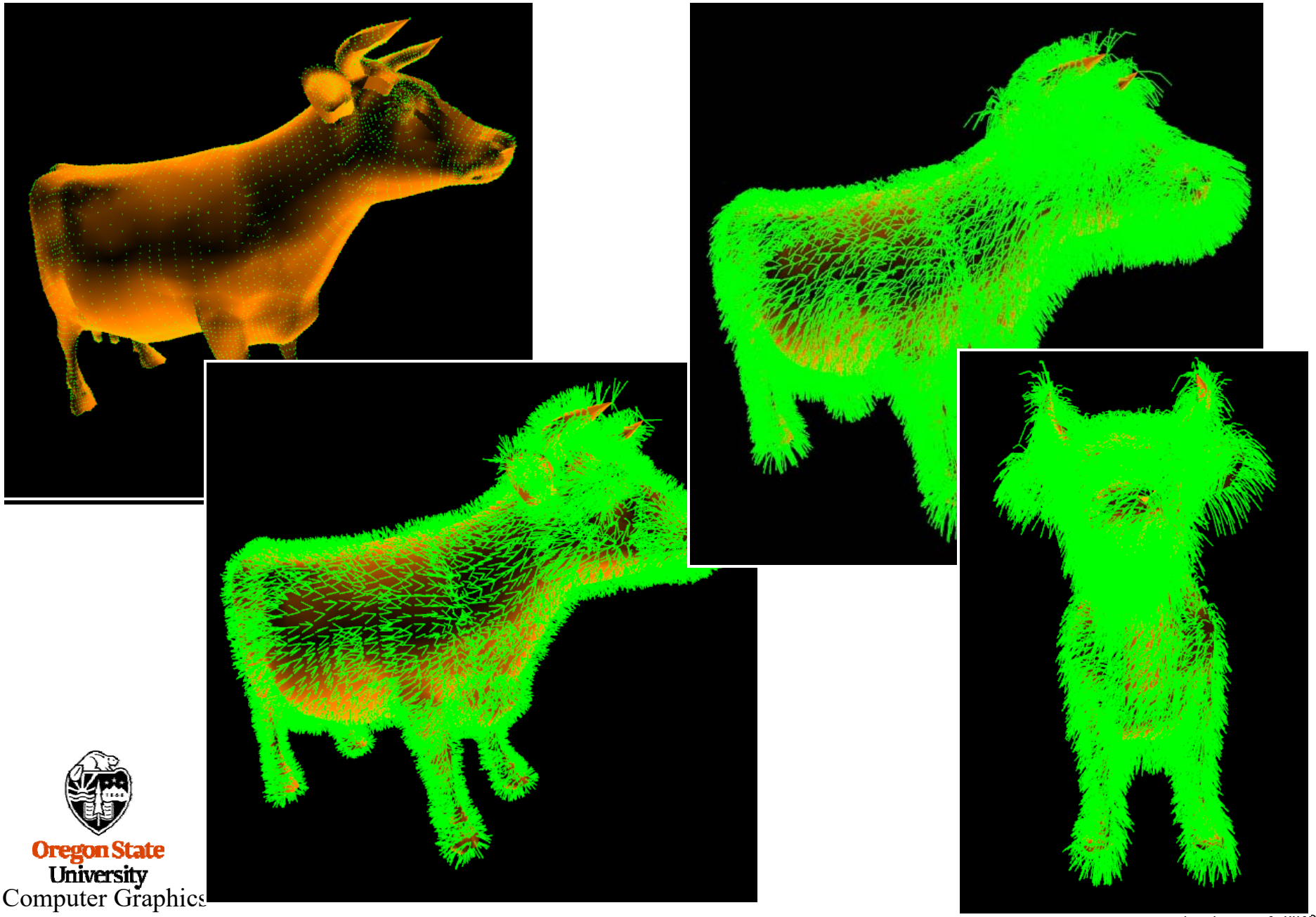
hedgehog.geom, III

```
        float dt = 1. / float( numLayers );
        float t = 1.;
        for( int it = 0; it <= numLayers; it++ )
        {
                float smax = 1. - t;

                int nums = it + 1;
                float ds = smax / float( nums - 1 );

                float s = 0.;
                for( int is = 0; is < nums; is++ )
                {
                        ProduceVertices( s, t );
                        s += ds;
                }

                t -= dt;
        }
}
```

Ducky Hedgehog Plot



Hedgehog Plots Gone Wild



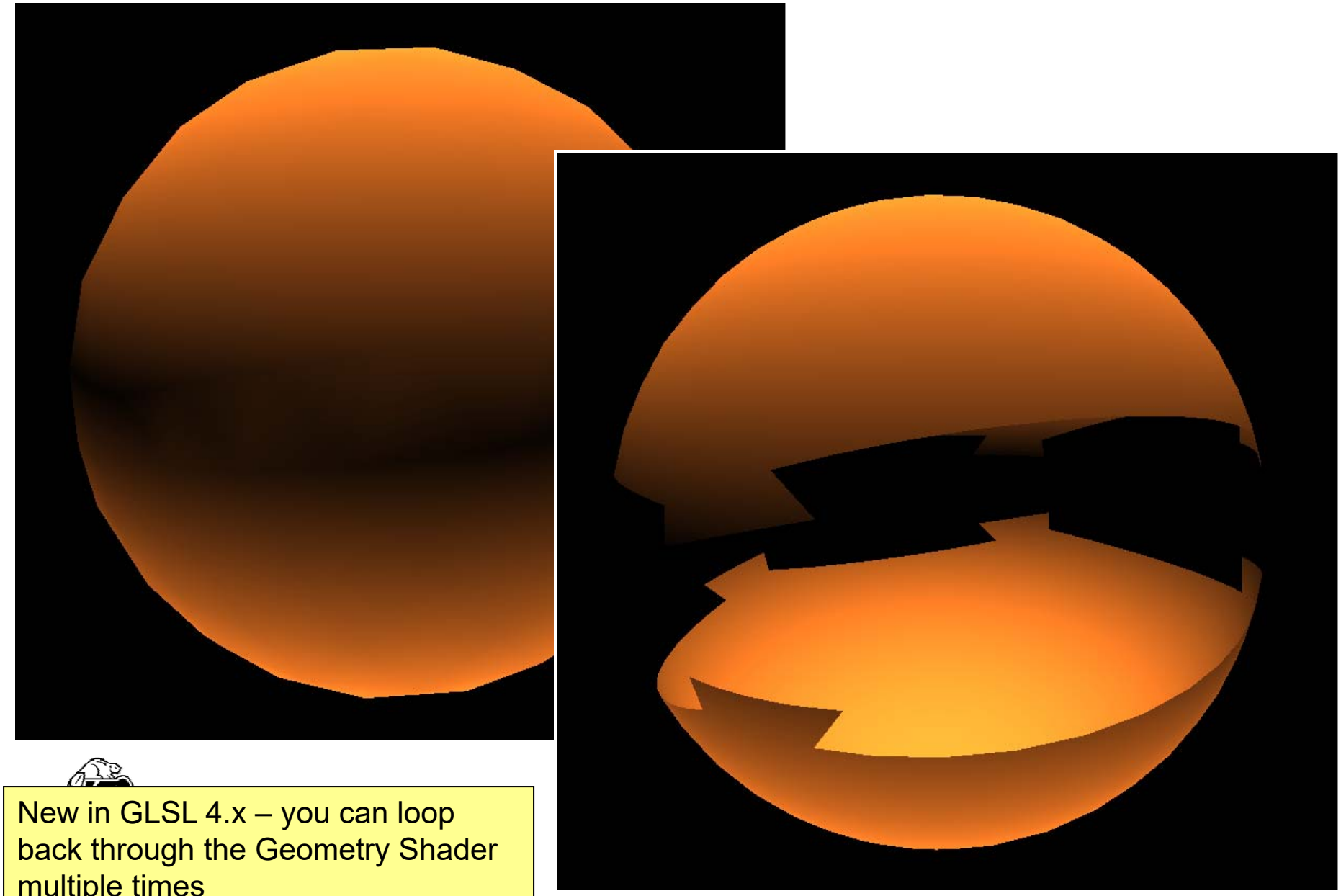
A GLSL Built-in Variable for the Geometry Shaders

int gl_PrimitiveIDIn

- **Tells the number of primitives processed since the last time glBegin( ) was called**
- **Calling a vertex array function counts as an implied glBegin( )**
- **gl_PrimitiveIDIn is 0 for the first primitive after the glBegin( )**

Geometry shaders can set the built-in variable gl_PrimitiveID to send a primitive number to the fragment shader

What Happens if you Exceed the Maximum Allowed Emitted Vertices?



New in GLSL 4.x – you can loop back through the Geometry Shader multiple times