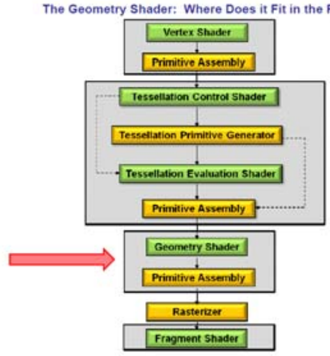
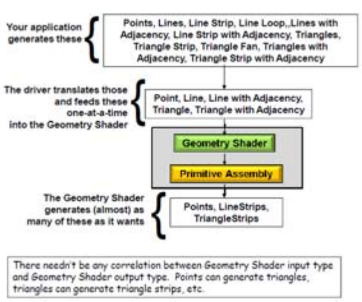
Geometry Shader

Thanks to Mike Bailey (OSU)

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



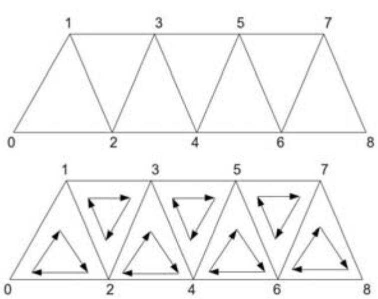
Geometry Shader: What Does it Do?



Geometry Shaders

- Can cull geometry (do front/back/arbitrary culling)
- Can amplify geometry (create geometry)
- Can emit different types than input
- Can generate multiple streams for single primitive

Strips (review)



Additional Types Introduced for Geometry Shader

GL_LINES_ADJACENCY

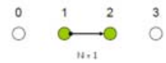
GL_LINE_STRIP_ADJACENCY

GL_TRIANGLES_ADJACENCY

GL_TRIANGLE_STRIP_ADJECENCY

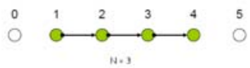
Adjacency Primitives (and what they do by default)

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.

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Lines with Adjacency

Lines stips with Adjacency

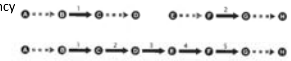
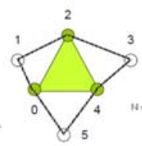


Figure 8.20: Lines produced using lines with adjacency primitives

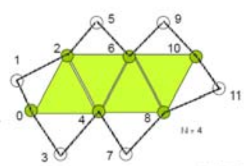
Adjacency Primitives (and what they do by default)

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.

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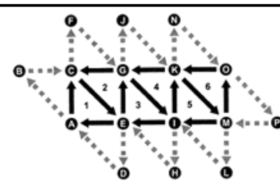

Figure 8.22: Triangles produced using GL_TRIANGLE_STRIP_ADJACENCY

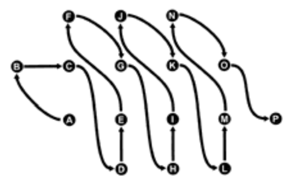

Figure 8.23: Ordering of vertices for GL_TRIANGLE_STRIP_ADJACENCY

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
gl_Layer	→ gl_LayerIn[■]	→ gl_Layer
"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

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

gl_Position
gl_PointSize
gl_Layer
gl_PrimitiveID

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 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( )" routine. 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.

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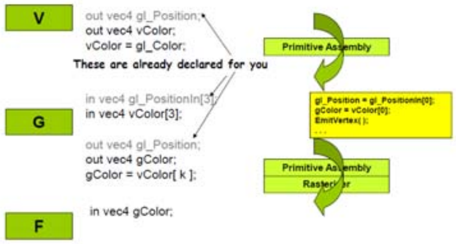
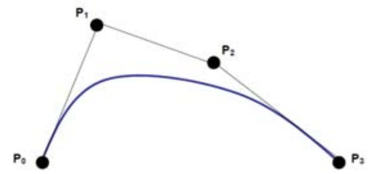
If you are using a Geometry Shader, then the GS must be used if you want to pass information from the Vertex Shader to the Fragment Shader



Example: A Bézier Curve



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

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

Lines Adjacency used for four points
(0, 0, 0)
(1, 1, 1)
(2, 1, 2)
(3,-1, 0)

beziercurve.vert

```
void main( )
{
        gl_Position = uModelViewProjectionMatrix * aVertex;
}
```

beziercurve.frag

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

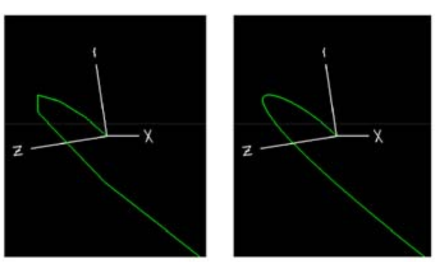

Example: Expanding 4 Points into a Bezier Curve with a Variable Number of Line Segments

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



Num = 5　　　　Num = 25

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

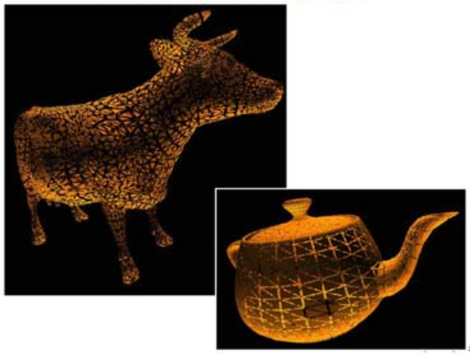
beziercurve.vert

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

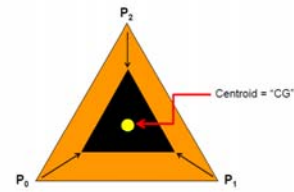
beziercurve.geom

```
. . .
                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 = uModelViewProjectionMatrix * xyzw;
                EmitVertex()
                t += dt;
        }
}
```

Another Example: Shrinking Triangles



Example: Shrinking Triangles



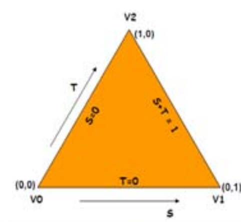
$CG = (P_0 + P_1 + P_2) / 3.;$
$P_0' = CG + uShrink * (P_0 - CG)$
$P_1' = CG + uShrink * (P_1 - CG)$
$P_2' = CG + uShrink * (P_2 - CG)$

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 = uModelViewProjectionMatrix * 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 );
}
```

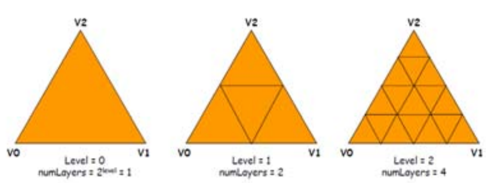
Another Example: Sphere Subdivision

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



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

Example: Sphere Subdivision



Example: Sphere Subdivision

spheresubd.vert

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

```
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.]
```

spheresubd.frag

```
uniform vec4 uColor;
in float gLightIntensity;
out vec4 fFragColor;

void
main( )
{
          fFragColor = 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( uNormalMatrix * n );  // the transformed normal

        vec4 ECposition = uModelViewMatrix * vec4( (uRadius*v), 1. );
        g LightIntensity  = dot( normalize(LIGHTPOS - ECposition.xyz), tnorm );
        g LightIntensity = abs( LightIntensity );

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


Example: Sphere Subdivision

spheresubd.geom

```
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.]
```

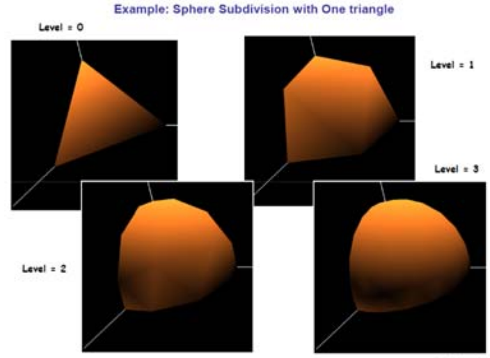
```
void
main( )
{
        V01 = ( gl_PositionIn[1] - gl_PositionIn[0] ).xyz;
        V02 = ( gl_PositionIn[2] - gl_PositionIn[0] ).xyz;
        V0  =   gl_PositionIn[0].xyz;

        int numLayers = 1 << uLevel;

        float dt = 1. / float( numLayers );

        float t_top = 1.;

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


Example: Sphere Subdivision

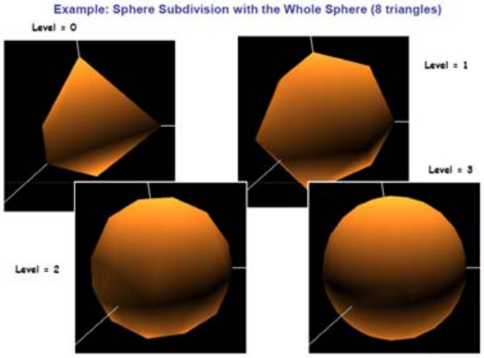
spheresubd.geom

```
        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;
        }
}
```

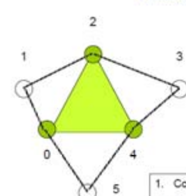

Example: Sphere Subdivision with One triangle



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



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 and the z component of an adjacent triangle, draw their common edge

Example: Silhouettes

silh.vert

```
void main( )
{
        gl_Position = uModelViewMatrix * aVertex;
}
```

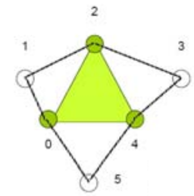
silh.frag

```
uniform vec4 uColor;
out vec4 fFragColor;

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

Example: Silhouettes

silh.geom

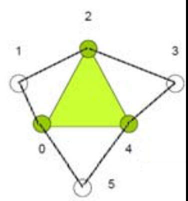
```
#version 330 compatibility
#extension GL_EXT_gpu_shader4: enable
#extension GL_EXT_geometry_shader4: enable
layout( triangles_adjacency ) in;
layout( line_strip, max_vertices=200 ) out;

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 );
        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. )
                N021 = vec3(0.,0.,0.) - N021;

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

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



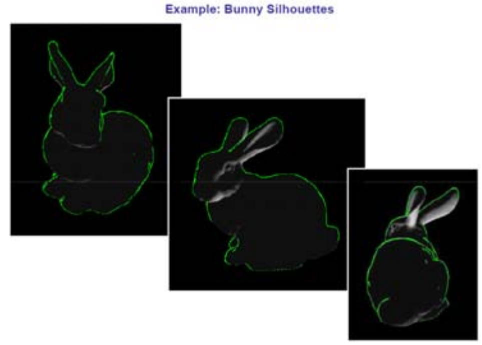
Example: Silhouettes

silh.geom

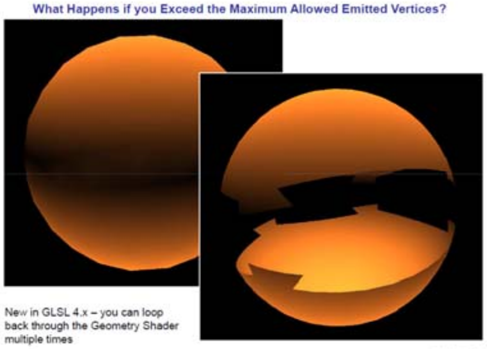
```
        if( N042.z * N021.z <= 0. )
        {
                gl_Position = uProjectionMatrix * vec4( V0, 1. );
                EmitVertex();
                gl_Position = uProjectionMatrix * vec4( V2, 1. );
                EmitVertex();
                EndPrimitive();
        }

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

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



Example: Bunny Silhouettes



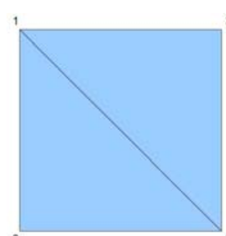
What Happens if you Exceed the Maximum Allowed Emitted Vertices?



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

Geom Shader Billboards

- Goal: create a quad (just a tri-strip)



Geom Shader Billboards

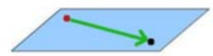
Need the quad to face the camera

- Consider camera (black) and billboard location (red) in world space

Geom Shader Billboards

Need the quad to face the camera

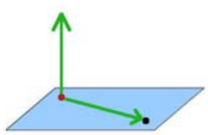
- Consider camera (black) and billboard location (red) in world space
- Create a vector from the billboard to the camera



Geom Shader Billboards

Need the quad to face the camera

- Consider camera (black) and billboard location (red) in world space
- Create a vector from the billboard to the camera
- Add an 'up' vector



Geom Shader Billboards

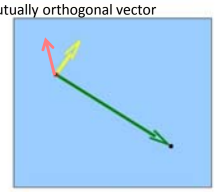
Need the quad to face the camera

- Consider camera (black) and billboard location (red) in world space
- Create a vector from the billboard to the camera
- Add an 'up' vector
- Make a mutually orthogonal vector (billboard location and range)

Geom Shader Billboards

Need the quad to face the camera

- Consider camera (black) and billboard location (red) in world space
- Create a vector from the billboard to the camera
- Add an 'up' vector
- Make a mutually orthogonal vector (billboard location and range)
- Then the third mutually orthogonal vector



Geom Shader Billboards

- VS

```
#version 330

layout (location = 0) in vec3 Position;

void main()
    {
        gl_Position = vec4(Position, 1.0);
    }
```

- FS

```
#version 330
uniform sampler2D gColorMap;

in vec2 TexCoord;
out vec4 FragColor;

void main()
{
    FragColor = texture2D(gColorMap, TexCoord);

    if (FragColor.r == 0 && FragColor.g == 0 && FragColor.b == 0) {
        discard;
    }
}
```

Geom Shader Billboards

- GS

```
#version 330

    layout (points) in;
    layout (triangle_strip) out;
    layout (max_vertices = 4) out;
    uniform mat4 gVP;
    uniform vec3 gCameraPos;
    uniform float size;

    out vec2 TexCoord;
    void main()
    {
      vec3 Pos = gl_in[0].gl_Position.xyz;
      vec3 toCamera = normalize(gCameraPos - Pos);
      vec3 up = vec3(0.0, 1.0, 0.0);
      vec3 right = cross(toCamera, up);
      vec3 newUp = cross(right, toCamera);


      vec3  ll = Pos - (right - newUp) * size);
      gl_Position = gVP * vec4(ll, 1.0);
      TexCoord = vec2(0.0, 0.0);
      EmitVertex();

      vec3 ul == Pos - (right + newUp) * size);
      gl_Position = gVP * vec4(ul, 1.0);
      TexCoord = vec2(0.0, 1.0);
      EmitVertex();

      vec3 lr == Pos + (right - newUp) * size);
      gl_Position = gVP * vec4(lr, 1.0);
      TexCoord = vec2(1.0, 0.0);
      EmitVertex();

      vec3 ur == Pos + (right + newUp) * size);
      gl_Position = gVP * vec4(ur, 1.0);
      TexCoord = vec2(1.0, 1.0);
      EmitVertex();

      EndPrimitive();
    }
```

Demo normal offset
(from superBible)

Demo Explosion
(from superBible)

Demo 4-views
(from superBible)

GS Quads (bi-linear interpolation)
(from superBible)

GS Culling
(from superBible)

The Difference Between Tessellation Shaders and Geometry Shaders

By now, you are probably confused about when to use a Geometry Shader and when to use a Tessellation Shader. Both are capable of creating new geometry from existing geometry. See if this helps.

Use a **Geometry Shader** when:

1. You need to convert geometry topologies, such as the silhouette and hedgehog shaders (triangles→lines) or the explosion shader (triangles→points)

2. You need some sort of geometry processing to come after the Tessellation Shader (such as how the shrink shader was used here)

Use a **Tessellation Shader** when you need to generate many new vertices and one of the tessellation topologies will suit your needs.

Use a **Tessellation Shader** when you need more than 6 input vertices to define the surface being tessellated..