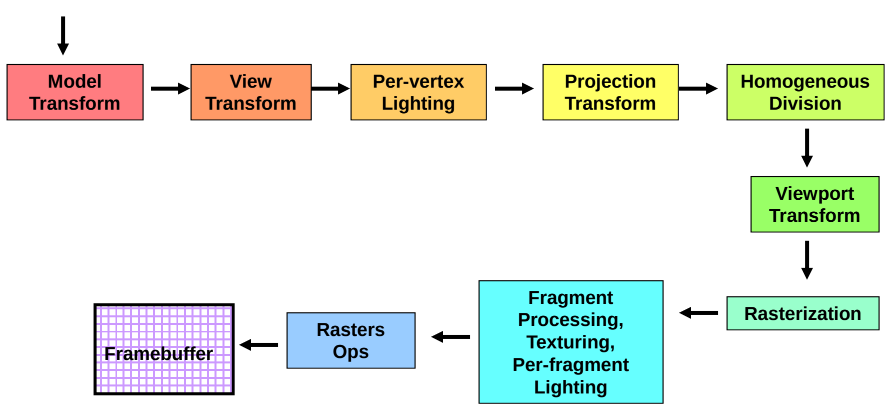
Introduction to Shaders for Visualization

Mike Bailey

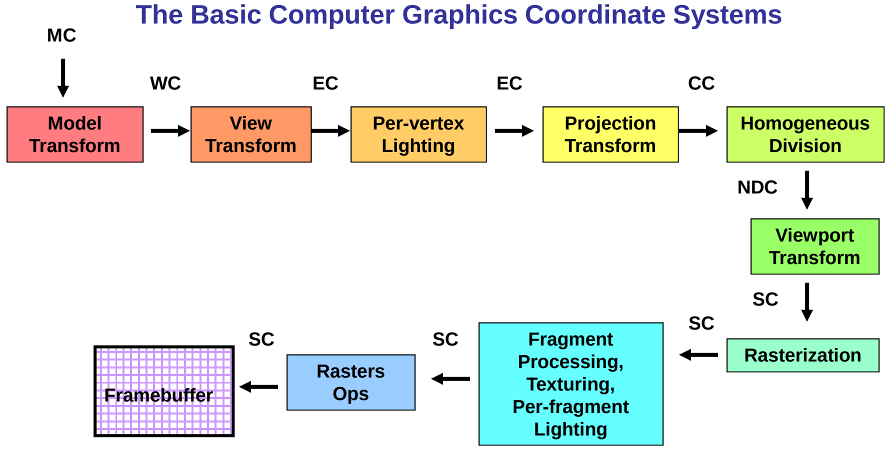
mjb@cs.oregonstate.edu

Oregon State University

The Basic Computer Graphics Pipeline

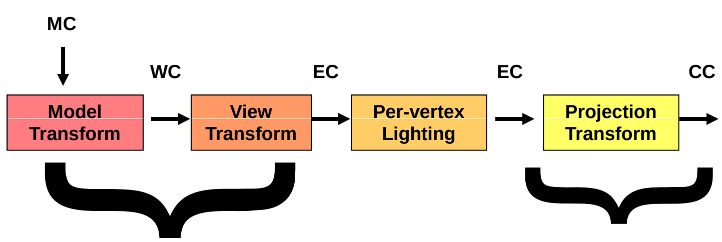


The Basic Computer Graphics Coordinate Systems



MC = Model Coordinates
WC = World Coordinates
EC = Eye Coordinates
CC = Clip Coordinates
NDC = Normalized Device Coordinates
SC = Screen Coordinates

OpenGL gives you Access to two Transformations



These two are lumped together into a single matrix called the *ModelView Matrix*.

In GLSL, this is called **gl_ModelViewMatrix**

This one is called the *Projection Matrix*.

In GLSL, this is called **gl_ProjectionMatrix**

GLSL also provides you with these two already multiplied together.

This is called **gl_ModelViewProjectionMatrix**

MC = Model Coordinates
WC = World Coordinates
EC = Eye Coordinates
CC = Clip Coordinates

What does a Vertex Shader Do?

The basic function of a vertex shader is to take the vertex coordinates as supplied by the application, and perform whatever transformation of them is required. At the same time, the vertex shader can perform various analyses based on those vertex coordinates and prepare variable values for later on in the graphics process.

Here's What a Shader Looks Like

```
varying vec4 Color;
varying float X, Y, Z;
varying float LightIntensity;

void
main( void )
{
        vec3 TransNorm = normalize( gl_NormalMatrix * gl_Normal );
        vec3 LightPos = vec3( 0., 0., 10. );
        vec3 ECposition = ( gl_ModelViewMatrix * gl_Vertex ).xyz;
        LightIntensity  = dot( normalize(LightPos - ECposition), TransNorm );
        LightIntensity = abs( LightIntensity );
        Color = gl_Color;
        vec3 MCposition = gl_Vertex.xyz;

        X = MCposition.x;
        Y = MCposition.y;
        Z = MCposition.z;

        gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

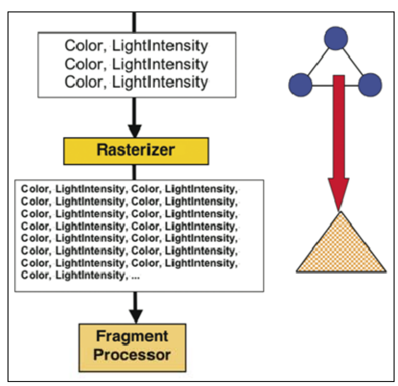
Don't worry about the details right now, just take comfort in the fact that it is C-like and that there appears to be a lot of support routines for you to use

A Vertex Shader Replaces These Operations:

- Vertex transformations
- Normal transformations
- Normal normalization
- Handling of per-vertex lighting
- Handling of texture coordinates

What does a Fragment Shader Do?

The basic function of a fragment shader is to take uniform variables, the output from the rasterizer, and texture information and then compute the color of the pixel for each fragment. This figure illustrates this process, showing first how the distinct vertices of a primitive are processed by the rasterizer to form the set of fragments that make up the primitive.



A Fragment Shader Replaces These Operations:

- Color computation
- Texturing
- Color arithmetic
- Handling of per-pixel lighting
- Fog
- Blending
- Discarding fragments

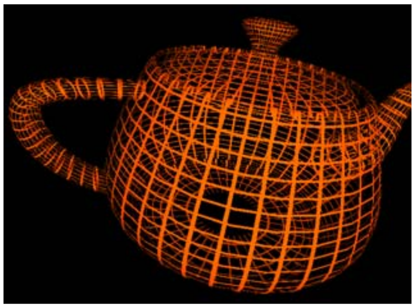
Simple Fragment Shader: Setting the Color

```
varying float LightIntensity;
uniform vec4 Color;
void main( )
{
        gl_FragColor= vec4( LightIntensity * Color.rgb, 1. );
}
```

```
varying vec3 myColor;
void main(void)
{
        gl_FragColor = vec4( myColor, 1.0 );
}
```

Fragment Shader: Discarding Fragments

```
varying vec4 Color;
varying float  LightIntensity;

uniform float  Density;
uniform float  Frequency;

void main( )
{
   vec2 st = gl_TexCoord[0].st;

   vec2 stf = st * Frequency;

   if( all( fract( stf ) >= Density )  )
      discard;

   gl_FragColor = vec4( LightIntensity*Color.rgb, 1. );
}
```



Sample Vertex Shader: Stripes in Model and Eye Coordinates

```
varying vec4 Color;
varying float X, Y, Z;
varying float LightIntensity;

void
main( void )
{
        vec3 TransNorm = normalize( gl_NormalMatrix * gl_Normal );
        vec3 LightPos = vec3( 0., 0., 10. );
        vec3 ECposition = ( gl_ModelViewMatrix * gl_Vertex ).xyz;
        LightIntensity  = dot(normalize(LightPos - ECposition), TransNorm);
        LightIntensity = abs( LightIntensity );
        Color = gl_Color;
        vec3 MCposition = gl_Vertex.xyz;
#ifdef EYE_COORDS
        X = ECposition.x;
        Y = ECposition.y;
        Z = ECposition.z;
#endif
#ifdef MODEL_COORDS
        X = MCposition.x;
        Y = MCposition.y;
        Z = MCposition.z;
#endif
        gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

The Fragment shader then sets the color based on the X value.

Sample Frament Shader: Stripes in Model and Eye Coordinates

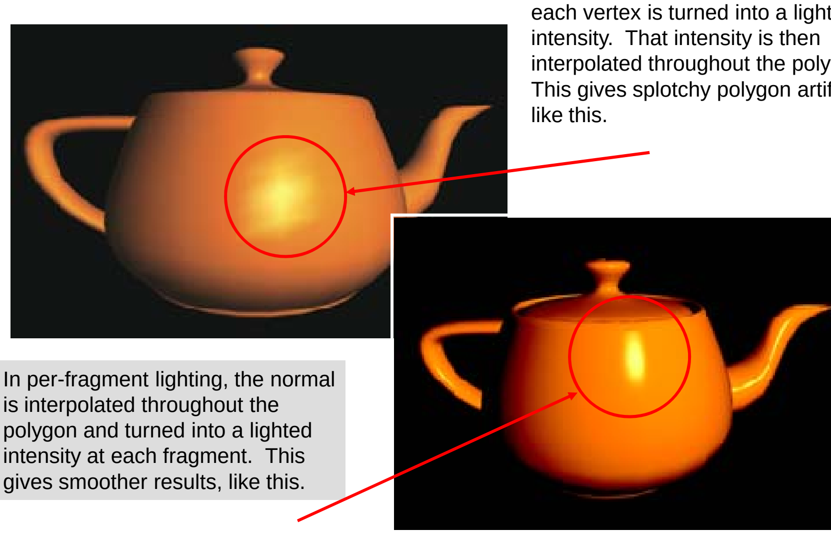
```
varying vec4 Color;
varying float X, Y, Z;
varying float LightIntensity;

uniform float A;
uniform float P;
uniform float Tol;

void
main( void )
{
	const vec3 WHITE = vec4( 1., 1., 1. );

	float f = fract( A*X );

	float t = smoothstep( 0.5-P-Tol, 0.5-P+Tol, f )  -  smoothstep( 0.5+P-Tol, 0.5+P+Tol, f );

	vec3 color = mix( WHITE, Color.rgb, t );
	gl_FragColor= vec4( LightIntensity*color, 1. );
}
```


Sample Vertex Shader: Stripes in Model and Eye Coordinates

The 2 shaders might (momentarily) look the same, but they don't act the same !

Per-vertex vs. Per-fragment Lighting

In per-vertex lighting, the normal at each vertex is turned into a light intensity. That intensity is then interpolated throughout the polygon. This gives splotchy polygon artifacts, like this.



In per-fragment lighting, the normal is interpolated throughout the polygon and turned into a lighted intensity at each fragment. This gives smoother results, like this.

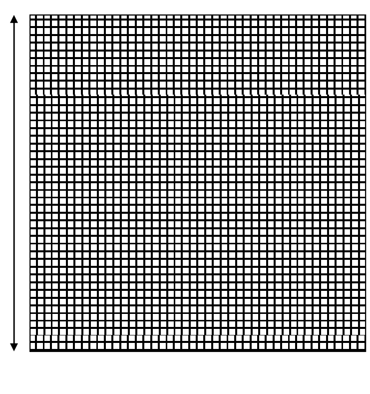
Think carefully about what you want as a varying variable – it can make a difference!

Image Basics

Treat the image as a texture and read it into the fragment shader

To get from the current texel to a neighboring texel, add ± (1./ResS , 1./ResT) to the current (S,T)

ResT

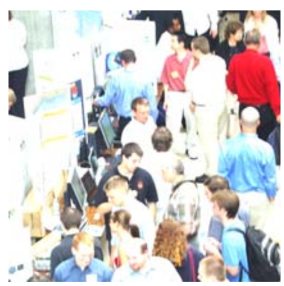


ResS

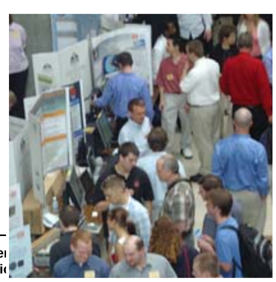
Image Negative

```
uniform sampler2D ImageUnit;

void main()
{
	vec2 st = gl_TexCoord[0].st;
	vec3 rgb = texture2D( ImageUnit,  st ).rgb;
	vec3 neg = vec3(1.,1.,1.) - rgb;
	gl_FragColor = vec4( neg, 1. );
}
```


Brightness



Contrast



Saturation

Sharpening

Edge Detection

Using Textures as Data

frag file, I

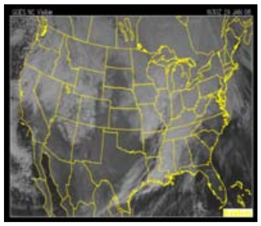
```
uniform sampler2D      VisibleUnit;
uniform sampler2D      InfraRedUnit;
uniform sampler2D      WaterVaporUnit;
uniform float          Visible;
uniform float          InfraRed;
uniform float          WaterVapor;
uniform float          VisibleThreshold;
uniform float          InfraRedThreshold;
uniform float          WaterVaporThreshold;
uniform float          Brightness;

void
main()
{
    vec3 visibleColor   = texture2D( VisibleUnit, gl_TexCoord[0].st ).rgb;
    vec3 infraredColor  = texture2D( InfraRedUnit, gl_TexCoord[0].st ).rgb;
    infraredColor = vec3(1.,1.,1.) - infraredColor;
    vec3 watervaporColor = texture2D( WaterVaporUnit, gl_TexCoord[0].st ).rgb;

    vec3 rgb;
```


Using Textures as Data

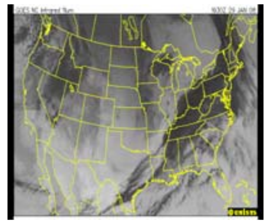
frag file, II

```
    if( visibleColor.r - visibleColor.g  > .25   &&   visibleColor.r - visibleColor.b > .25 )
    {
        rgb = vec3( 1., 1., 0. );       // state outlines become yellow
    }
    else
    {
        rgb = Visible*visibleColor  +  InfraRed*infraredColor  +  WaterVapor*watervaporColor;
        rgb /= 3.;
        vec3 coefs = vec3( 0.296, 0.240, 0.464 );
        float visibleInten = dot(coefs,visibleColor);
        float infraredInten = dot(coefs,infraredColor);
        float watervaporInten = dot(coefs,watervaporColor);
        if( visibleInten > VisibleThreshold  &&  infraredInten < InfraRedThreshold  &&  watervaporInten > WaterVaporThreshold )
        {
            rgb = vec3( 0., 1., 0. );
        }
        else
        {
            rgb *= Brightness;
            rgb = clamp( rgb, 0., 1. );
        }
    }

    gl_FragColor = vec4( rgb, 1. );
}
```

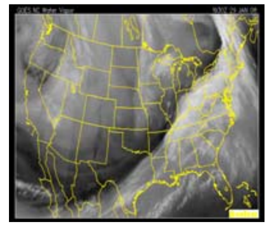
Using Textures as Data – Where is it Likely to Snow?



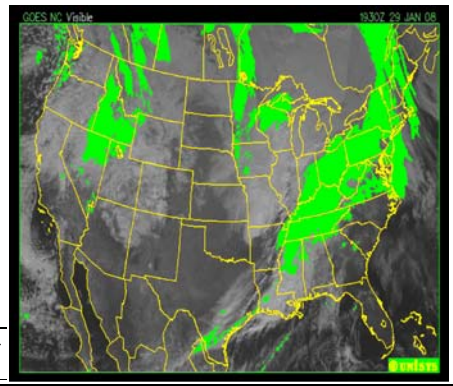
Visible



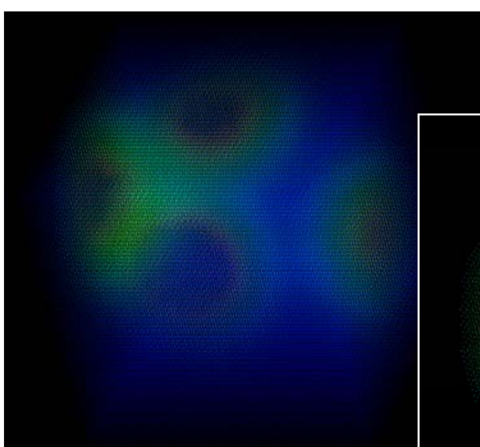
Infrared



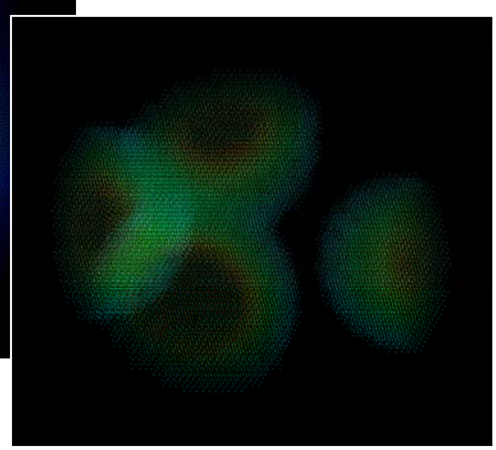
Water vapor



Point Cloud from a 3D Texture Dataset



Full data



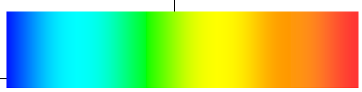
Low values culled

frag file

```
uniform float        Min;
uniform float        Max;
uniform sampler3D    TexUnit;

const float SMIN =   0.;
const float SMAX = 100.;


void
main( void )
{
      vec4 rgba = texture3D( TexUnit, gl_TexCoord[0].stp );
      float scalar = rgba.r;

      if( scalar < Min )
            discard;

      if( scalar > Max )
            discard;

      float t = ( scalar - SMIN ) / ( SMAX - SMIN );
      vec3 rgb = Rainbow( t );

      gl_FragColor = vec4( rgb, 1. );
}
```

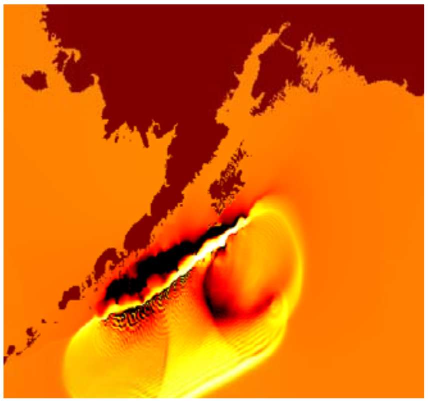

Visualization Transfer Functions

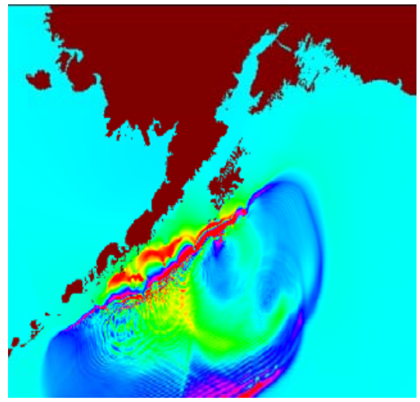
```
vec3
Rainbow( float t )
{
      t = clamp( t, 0., 1. );

      vec3 rgb;

      // b -> c
      rgb.r = 0.;
      rgb.g = 4. * ( t - (0./4.) );
      rgb.b = 1.;

      // c -> g
      if( t >= (1./4.) )
      {
            rgb.r = 0.;
            rgb.g = 1.;
            rgb.b = 1. - 4. * ( t - (1./4.) );
      }

      // g -> y
      if( t >= (2./4.) )
      {
            rgb.r = 4. * ( t - (2./4.) );
            rgb.g = 1.;
            rgb.b = 0.;
      }

      // y -> r
      if( t >= (3./4.) )
      {
            rgb.r = 1.;
            rgb.g = 1. - 4. * ( t - (3./4.) );
            rgb.b = 0.;
      }

      return rgb;
}
```



```
vec3
HeatedObject( float t )
{
      t = clamp( t, 0., 1. );

      vec3 rgb;
      rgb.r = 3. * ( t - (0./6.) );
      rgb.g = 0.;
      rgb.b = 0.;

      if( t >= (1./3.) )
      {
            rgb.r = 1.;
            rgb.g = 3. * ( t - (1./3.) );
      }

      if( t >= (2./3.) )
      {
            rgb.g = 1.;
            rgb.b = 3. * ( t - (2./3.) );
      }
```

Visualization -- Don't Send Colors to the GPU, Send the Raw Data

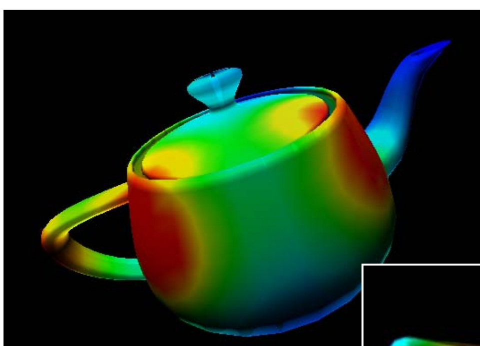


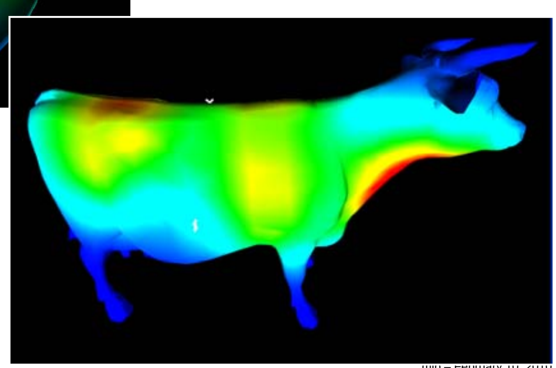


Use the GPU to turn the data into graphics on-the-fly

Visualization by Chris Janik

3D Probe – Assigning the Transfer Function to Arbitrary Geometry

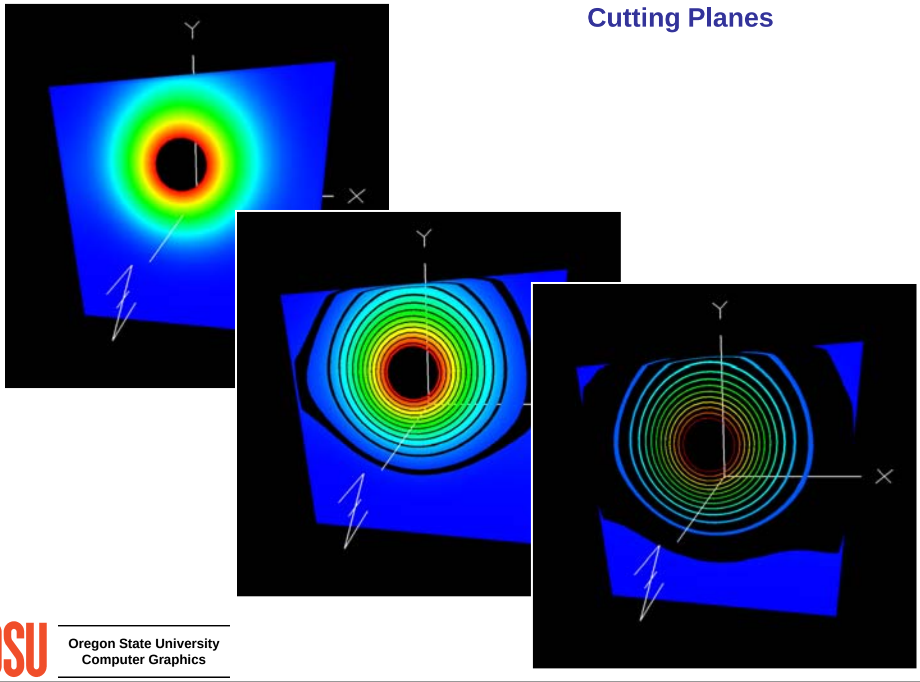




frag file

```
uniform float          Min;
uniform float          Max;
uniform sampler3D              TexUnit;
varying vec4           ECposition;

const float SMIN =   0.;
const float SMAX = 120.;


void
main( void )
{
        vec3 stp = clamp( ( ECposition.xyz + 1. ) / 2.,  0., 1. );      // maps [-1.,1.] to [0.,1.]

        vec4 rgba = texture3D( TexUnit, stp );
        float scalar = rgba.r;

        if( scalar < Min )
                discard;

        if( scalar > Max )
                discard;

        float t = ( scalar - SMIN ) / ( SMAX - SMIN );
        vec3 rgb = Rainbow( t );

        gl_FragColor = vec4( rgb, 1. );
}
```

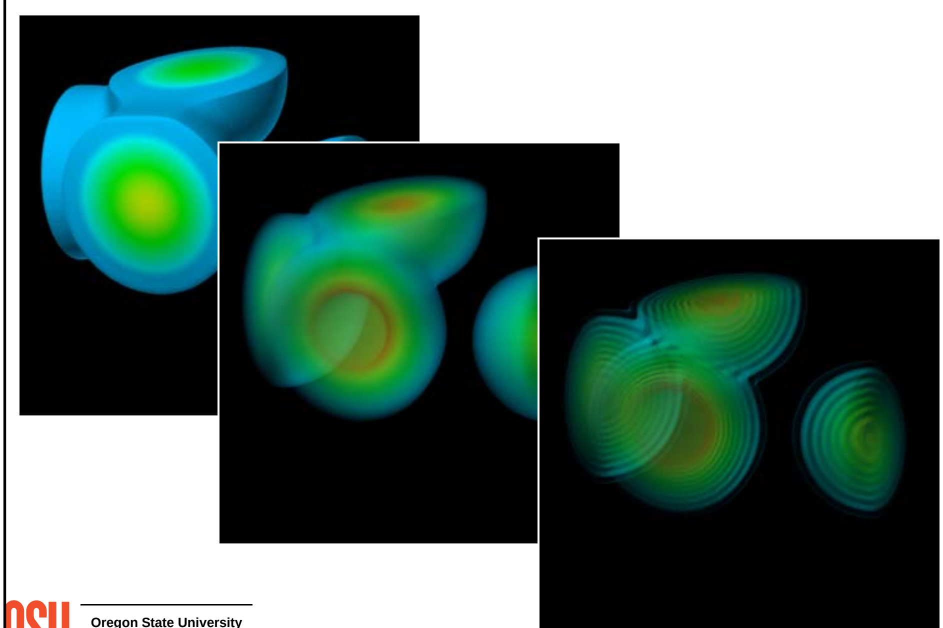

Cutting Planes



frag file

```
uniform float         Min;
uniform float         Max;
uniform sampler3D     TexUnit;
varying vec3          MCposition;

const float SMIN =   0.;
const float SMAX = 120.;

void
main( void )
{
      vec3 stp = ( MCposition + 1 ) / 2.;           // maps [-1.,1.] to [0.,1.]
      if( any(stp) < 0.  ||  any(stp) > 1. )
            discard;

      vec4 rgba = texture3D( TexUnit, stp );
      float scalar = rgba.r;

      if( scalar < Min  ||  scalar > Max )
            discard;

      float t = ( scalar - SMIN ) / ( SMAX - SMIN );
      vec3 rgb = Rainbow( t );
      //vec3 rgb = HeatedObject( t );

      gl_FragColor = vec4( rgb, 1., );
}
```


Volume Rendering – Ray Casting

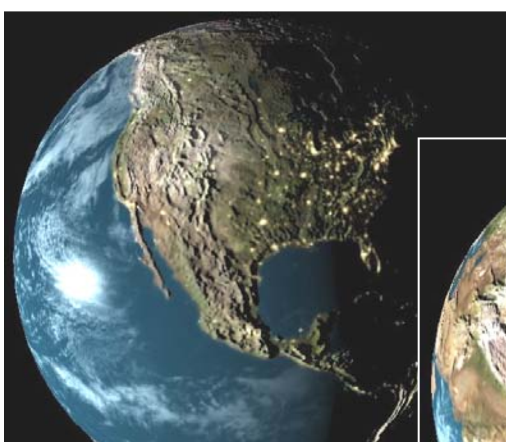


Extruding Shapes Along Flow Lines

Extruding a block arrow along a spiral flow line

Adding moving “humps” to create a peristaltic effect

Bump-Mapping for Terrain Visualization



Visualization by Nick Gebbie

Oregon State University
Computer Graphics