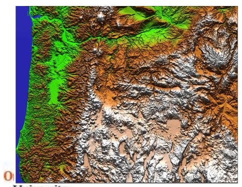
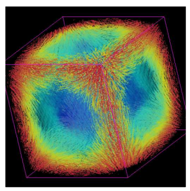
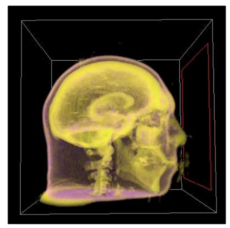
# Using Shaders to Enhance Scientific Visualizations

Oregon State University
Mike Bailey
mjb@cs.oregonstate.edu





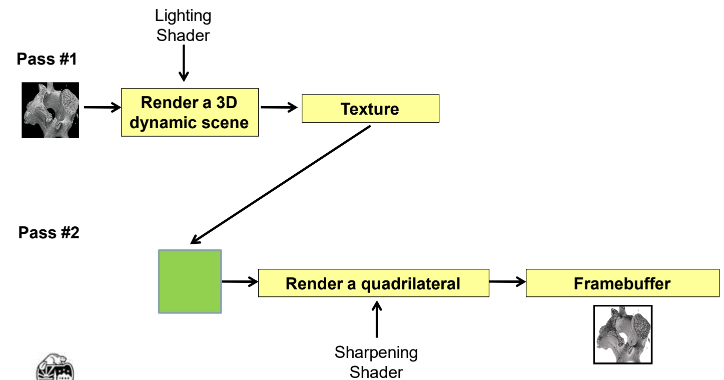








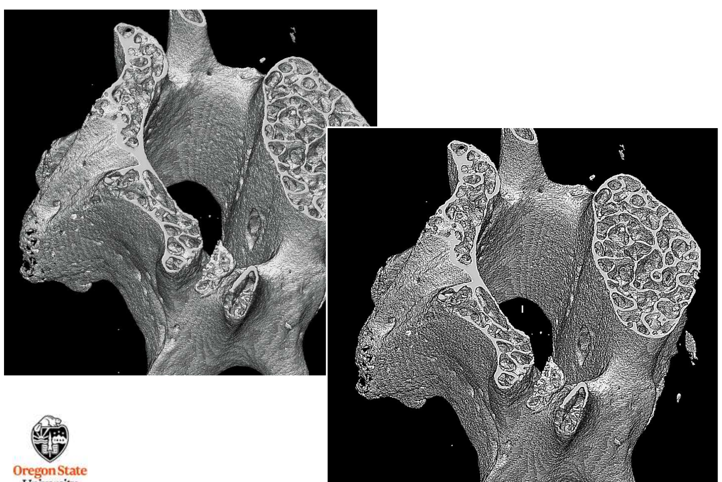
## You Can Do Image Processing on Dynamic Scenes with a Two-pass Approach







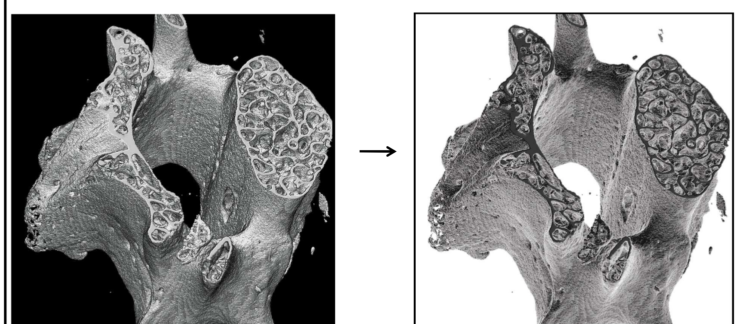

## Visualization Imaging -- Sharpening







## Surprisingly, the negative of a 3D object often reveals additional details



## Embossing

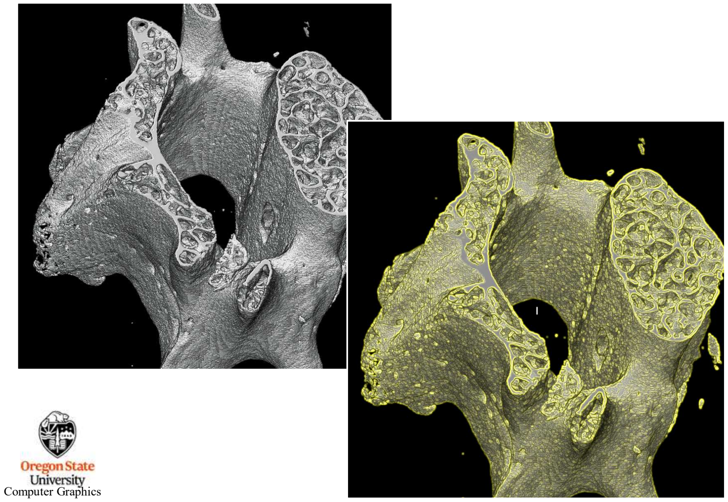


Changing the emboss angle is interesting.



## Visualization Imaging – Edge Detection

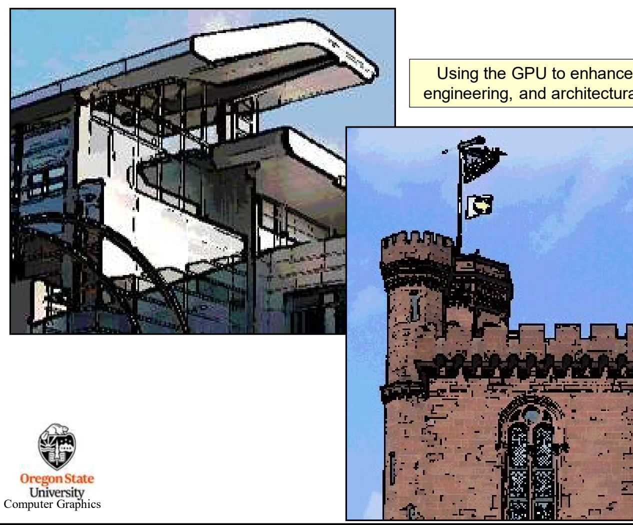






## Toon Rendering for Non-Photorealistic Effects



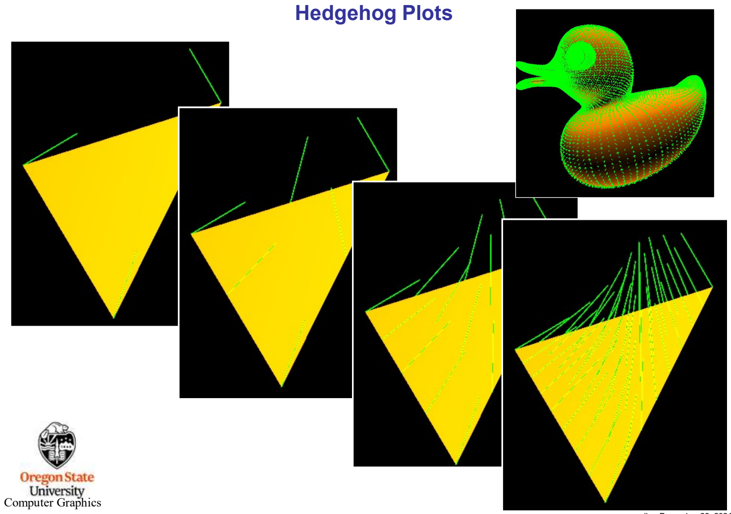


Using the GPU to enhance scientific, engineering, and architectural illustration



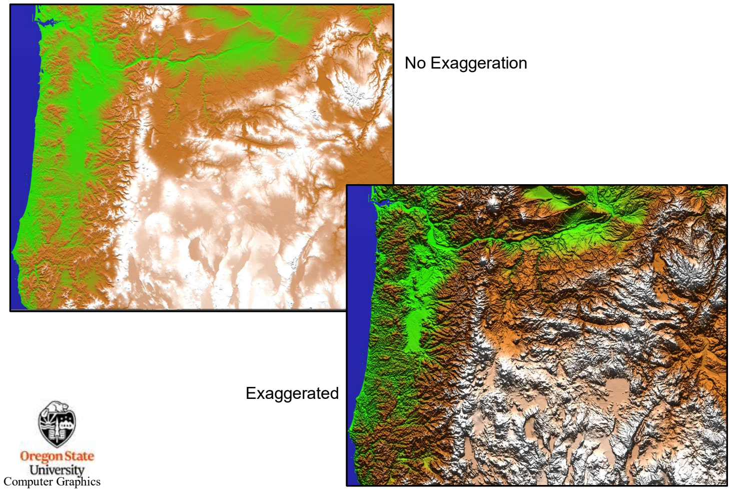
## A Vector Visualization Technique: Hedgehog Plots





## Terrain Height Bump-mapping





No Exaggeration

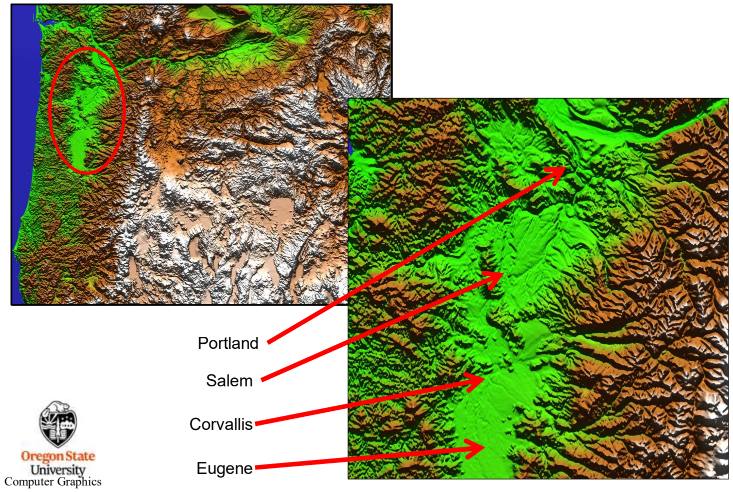
Exaggerated

Oregon State University Computer Graphics



## Terrain Height Bump-mapping






Oregon State University Computer Graphics



## Bump-Mapping for Terrain Visualization



Visualization by Nick Gebbie

Oregon State University Computer Graphics

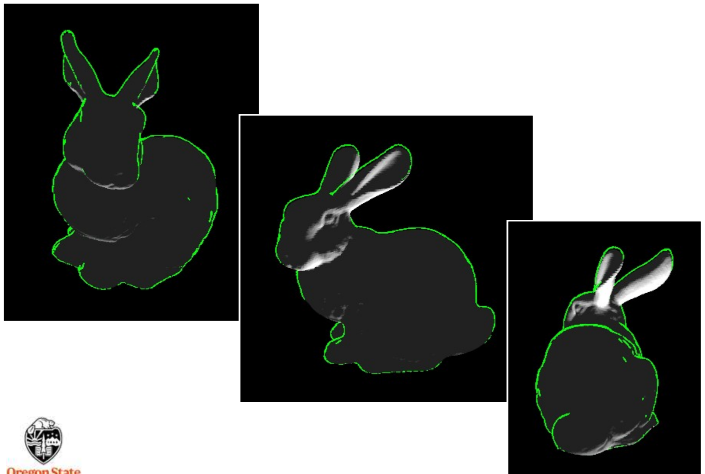


## 3D Object Silhouettes – Fragment Shader Version



Oregon State University Computer Graphics

## 3D Object Silhouettes – Geometry Shader Version



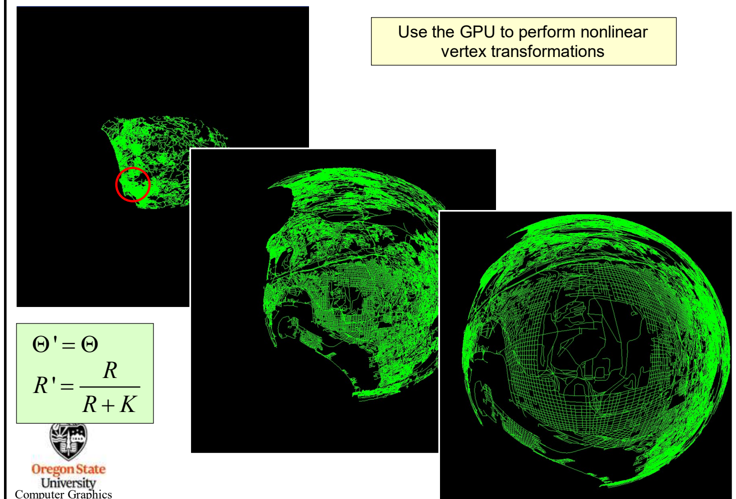
Oregon State University Computer Graphics





## Visualization -- Polar Hyperbolic Space

Use the GPU to perform nonlinear vertex transformations



$$\Theta' = \Theta$$

$$R' = \frac{R}{R+K}$$

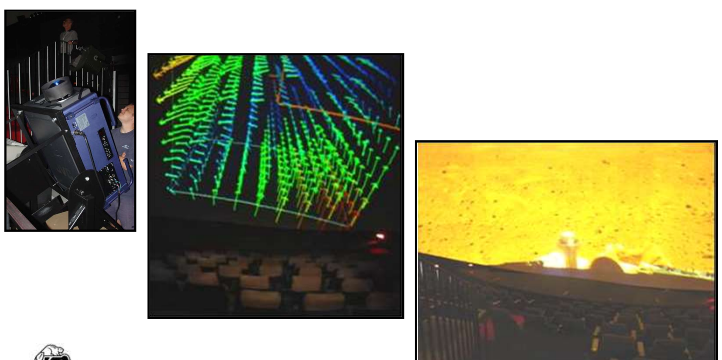
Oregon State University Computer Graphics





## Dome Projection for Immersive Visualization

Use the GPU to perform nonlinear vertex transformations

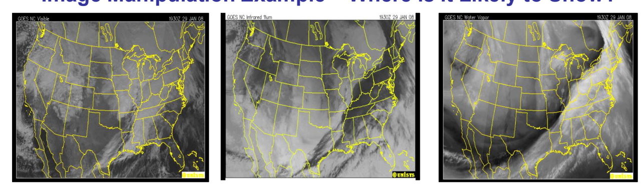


Oregon State University Computer Graphics



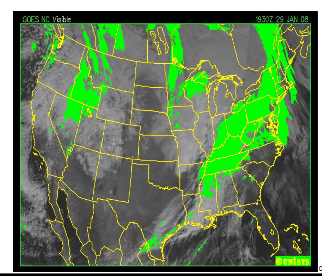


## Image Manipulation Example – Where is it Likely to Snow?



Visible | Infrared | Water vapor

```
if( have_clouds  &&  have_a_low_temperature  &&  have_water_vapor )
        color = green;
else
        color = from visible map
```




Oregon State University Computer Graphics

## Writing 3D Point Cloud Data into a Floating-Point Texture for *glman*

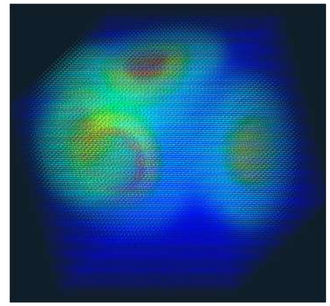
```
fwrite( &nums, 4, 1, fp );
fwrite( &numt,  4, 1, fp );
fwrite( &nump, 4, 1, fp );

for( int p = 0; p < nump; p++ )
{
        for( int t = 0; t < numt; t++ )
        {
                for( int s = 0; s < nums; s++ )
                {
                        float red, green, blue, alpha;
                        << assign red, green blue, alpha >>
                        fwrite( &red,     4, 1, fp );
                        fwrite( &green, 4, 1, fp );
                        fwrite( &blue,    4, 1, fp );
                        fwrite( &alpha,  4, 1, fp );
                }
        }
}
```

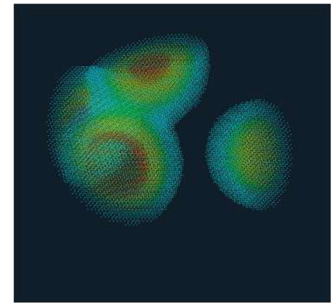




## Point Cloud from a 3D Texture Dataset

Low values culled





Full data





## Where to Place the Geometry?

I personally like thinking of the data as living in a cube that ranges from -1. to 1. in X, Y, and Z. It is straightforward to position geometry in this space and easy to view and transform it. This means that *any* 3D object in that space, not just a point cloud, can map itself to the 3D texture data space.

So, because the ***s*** texture coordinate goes from 0. to 1., then the linear mapping from the physical ***x*** coordinate to the texture ***s*** coordinate is:

$$-1. \leq x \leq 1. \Rightarrow s = \frac{x + 1.}{2.} \Rightarrow 0. \leq s \leq 1.$$

The same mapping applies to ***y*** and ***z*** to create the ***t*** and ***p*** texture coordinates.

In GLSL, this conversion can be done in one line of code using the vec3:

```
vec3 xyz = ???
. . .
vec3 stp  = ( xyz + 1. ) / 2.;
```

You can also go the other way: **vec3 xyz = -1. + ( 2. * stp );**





## The Vertex Shader

```
out vec3 vMC;

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

## The Fragment Shader



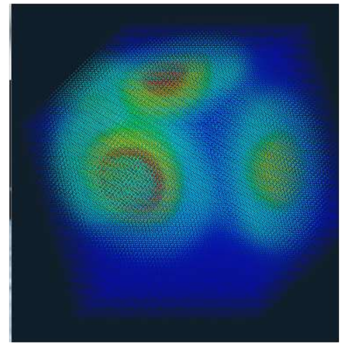
```
uniform float  uMin,  uMax;
uniform sampler3D  uTexUnit;
in vec3  vMC;
const float SMIN =     0.;
const float SMAX = 120.;

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

        if( any( lessThan( stp, vec3(0.,0.,0.) ) ) )
                discard;

        if( any( greaterThan( stp, vec3(1.,1.,1.) ) ) )
                discard;

        float scalar = texture( uTexUnit, stp ).r;      // data is hiding in the red component
        if( scalar < uMin  || scalar > uMax )
                discard;

        float t = ( scalar - SMIN ) / ( SMAX - SMIN );
        vec3 rgb = Rainbow( t );
        gl_FragColor = vec4( rgb, 1. );
}
```

SIMD functions to help GLSL if-tests



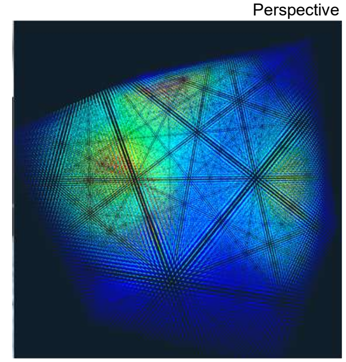
## A Problem with Uniform Pointclouds: Row-of-Corn and Moire Patterns





Orthographic

Perspective



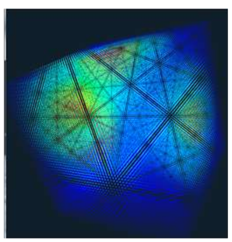


## Uniform Points vs. Jittered Points

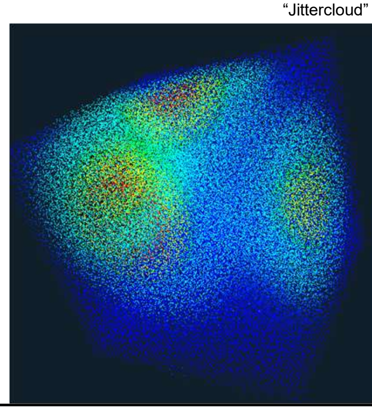


"Jittering" moves each point a small random amount in ±x, ±y, and ±z. Because our data value lookup comes from (s,t,p) which comes from (x,y,z), the lookup will be correct at the jittered points.

"Pointcloud"



"Jittercloud"



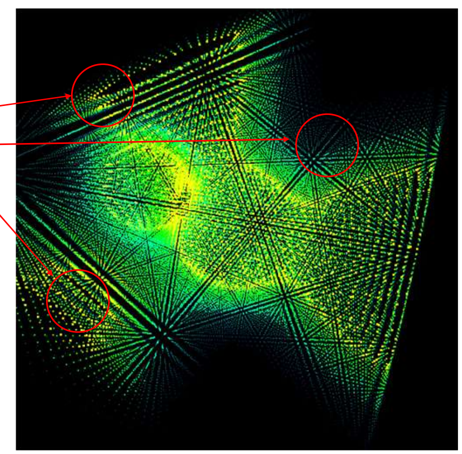


## Enhanced Point Clouds



The shaders can potentially change:

- Color
- Alpha
- Pointsize

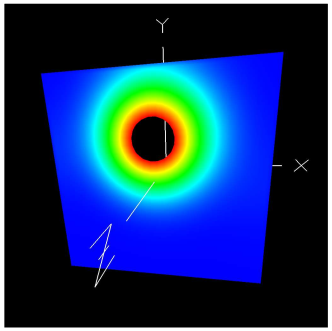


## Color Cutting Planes

Now, change the Point Cloud geometry to a quadrilateral geometry. If we keep the coordinate range from -1. to 1., then the same shader code will work, ***except that we now want to base the color assignment on Eye Coordinates instead of Model Coordinates***:

```
in vec3  vEC;

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

Eye (transformed) coordinates are being used here because the cutting plane is moving *through the data*.




Note that the plane can be oriented at any angle because the s-t-p data lookup comes from the *transformed* x-y-z coordinates of the cutting plane



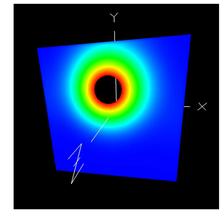




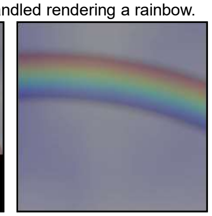
## Color Cutting Planes

The cutting plane is actually just being used as a ***fragment-generator***. Each fragment is then being asked "what data value lives at the same place you live"?

```
in vec3  vEC;

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




This is very much like how we handled rendering a rainbow.







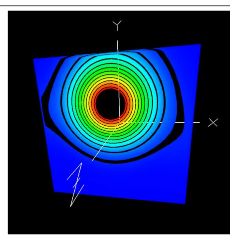


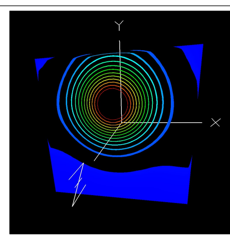
## Gapped-Contour Cutting Planes

Let's say that we want "contour gaps" at each 10 degrees of temperature. Then the main change to the shader will be that we need to find how close each fragment's interpolated scalar data value is to an even multiple of 10. To do this, we add this discretization code to the fragment shader:

```
float scalar10 = float( 10*int( (scalar+5.)/10. ) );
if( abs( scalar - scalar10 )  <  uTol )
        discard;
```

Notice that this uses a uniform variable called **uTol**, which is read from a slider and has a range of 0. to 5. **uTol** is used to determine how close to an even multiple of 10 degrees we will accept, and thus how thick we want the contour gaps to be.







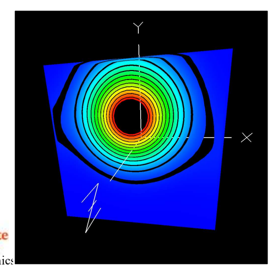


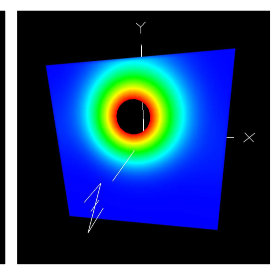

## Contour Cutting Planes are Also Color Cutting Planes

Note that when uTol=5., the uTol if-statement

```
float scalar10 = float( 10*int( (scalar+5.)/10. ) );
if( abs( scalar - scalar10 )  <  uTol )
        discard;
```

always fails, and we end up with the same display as we had with the interpolated colors. Thus, we wouldn't actually need a separate *color cutting plane* shader at all. Shaders that can do double duty are always appreciated!

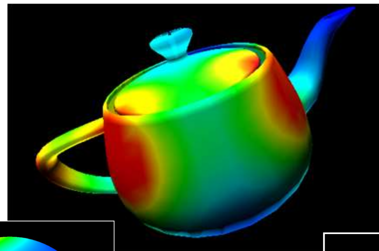


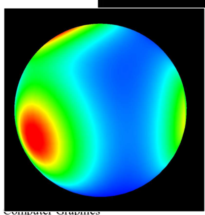



## 3D Data Probe – Mapping the Data to Arbitrary Geometry

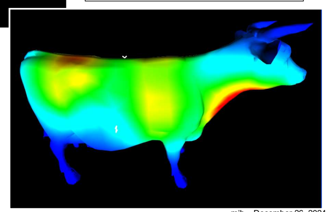


The cutting plane is actually being used as a fragment-generator. Each fragment is then being asked “what data value lives at the same place you live”?





Some shapes make better probes than others do… ☺





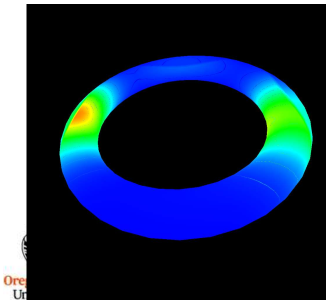
## An Observation

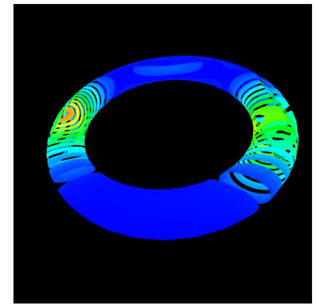


Note that Point Clouds, Jitter Clouds, Colored Cutting Planes, Contour Cutting Planes, and 3D Data Probes are *really all the same technique*!

They just vary in what type of geometry the data is mapped to. They use the same shader code, possibly with a switch between model and eye coordinates.

How about something less obvious like a torus?

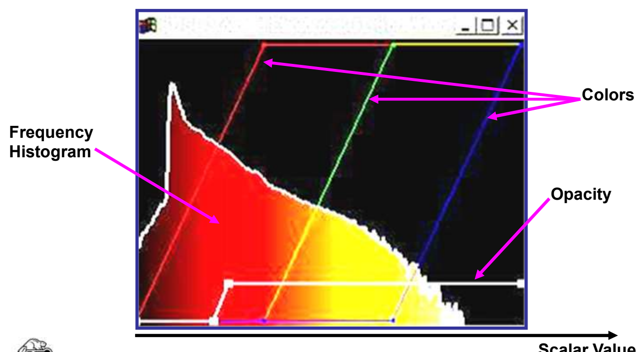






## Visualization Transfer Function – Relating Display Attributes to the Scalar Value



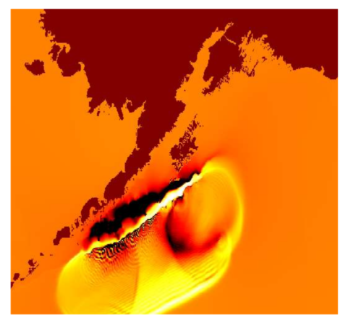


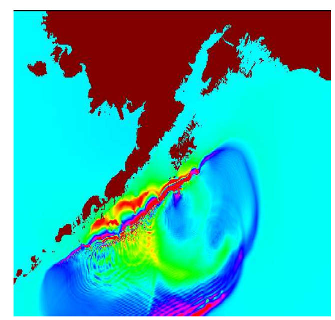

OSU *vx* Transfer Function Sculpting Window



## Visualization -- Don’t Send Colored Data to the GPU, Send the Raw Data and a Separate Transfer Function to the Fragment Shader







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

Visualizations by Chris Janik

## A Visualization Scenario

A thermal analysis reveals that a bar has a temperature of 0º at one end and 100º at the other end:


You want to color it with a rainbow scale as follows:


You also want to use smooth shading, so that you can render the bar as a single quadrilateral.

**Should you assign colors first then interpolate, or interpolate first then assign colors? Will it matter? If so, how?**



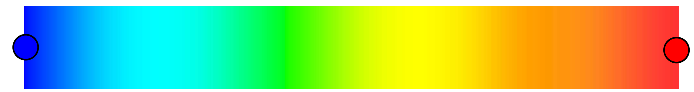


## A Visualization Scenario

Assign colors from temperatures, then interpolate:

***WRONG !***

Interpolate temperatures first, then assign colors:



***RIGHT !***

***Conclusion:*** *let the rasterizer interpolate your scalar values and let your fragment shader assign colors and alphas to those values*





## Point Clouds – Three Ways to Assign the Scalar Function

Without shaders:
Assigning colors first – problems with interpolation

```
glBegin( GL_POINTS );
    < convert s0 to r0,g0,b0, a0 >
    glColor4f( r0, g0, b0, a0 );
    glPointSize( p0 );
    glVertex3f( x0, y0, z0 );
    . . .
glEnd( );
```

With shaders”
Put the data in attribute variables

```
Pattern.Use( );
glBegin( GL_POINTS );
    Pattern.SetAttributeVariable( "Temperature", s0 );
   glVertex3f( x0, y0, z0 );
   . . .
glEnd( );
```





## Point Clouds – A Third Way – I *really* like this one

With shaders:
“Hiding” the scalar value in the *w* component

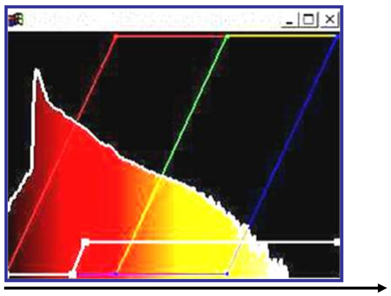
```
Pattern.Use( );
glBegin( GL_POINTS );
   glVertex4f( x0, y0, z0, s0 );
   . . .
glEnd( );
```

The hidden scalar value in the *w* component must be extracted and replaced with 1.0 in the vertex shader

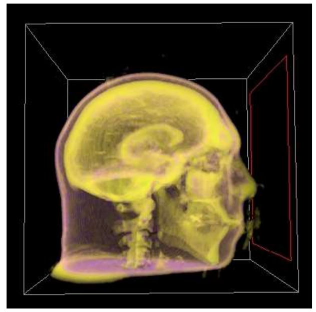
```
out float vScalar;

void
main( )
{
    vScalar = gl_Vertex.w;
    gl_Position = gl_ModelViewProjectionMatrix * vec4(gl_Vertex.xyz, 1. );
}
```

## Volume Rendering – a different way to think of visualizing 3D Scalar Data

Each voxel has a color and opacity depending on its scalar value




OSU *vx* Transfer Function Sculpting Window



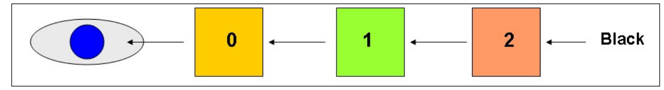
Visualization by Ankit Khare





## Volume Rendering – Compositing via Ray Casting

**Thinking about it back-to-front:**




$$color_{12} = \alpha_2 color_2 + (1-\alpha_2) black,$$

$$color_{01} = \alpha_1 color_1 + (1-\alpha_1) color_{12},$$

$$color^* = \alpha_0 color_0 + (1-\alpha_0) color_{01}.$$

**Gives the front-to-back equation:**

$$color^* = \alpha_0 color_0 + (1-\alpha_0)\alpha_1 color_1 + (1-\alpha_0)(1-\alpha_1)\alpha_2 color_2 + (1-\alpha_0)(1-\alpha_1)(1-\alpha_2) black.$$





## Volume Rendering – Compositing via Ray Casting

**uMin** = minimum scalar value to display

**uMax** = maximum scalar value to display

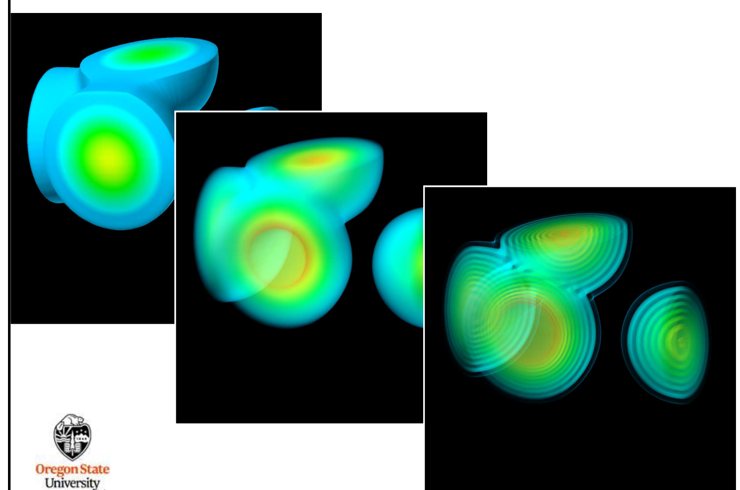
**uAmax** = alpha value to use if this voxel is to be seen

```
float   astar = 1.;
vec3  cstar = vec3( 0., 0., 0. );
for( int i = 0; i < uNumSteps; i++, STP += uDirSTP )
{
        if(  any(     lessThan( STP, vec3(0.,0.,0.) ) )  )
                continue;

        if(  any( greaterThan( STP, vec3(1.,1.,1.) ) )  )
                continue;

        float scalar = texture3D( uTexUnit, STP ).r;
        if( scalar < uMin )
                continue;
        if( scalar > uMax )
                continue.;
        float alpha = uAmax;

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

        cstar += astar * alpha * rgb;
        astar *= ( 1. - alpha );

        // break out if the rest of the tracing won't matter:

        if( astar == 0. )
                break;
}
 gl_FragColor = vec4( cstar, 1. );
```

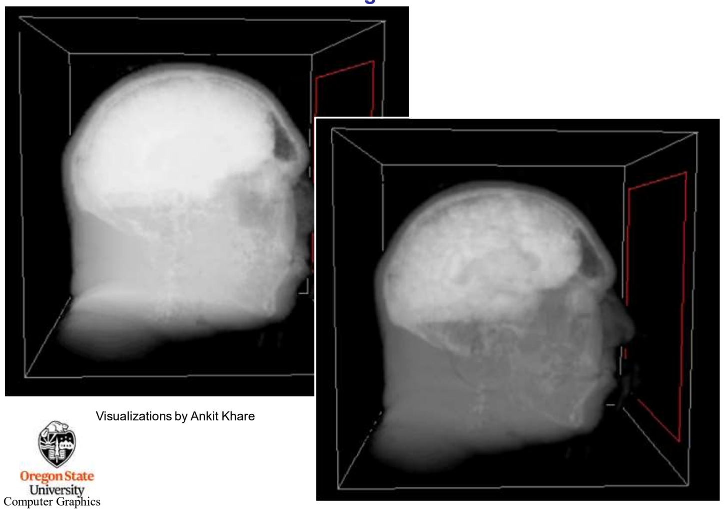




## Volume Rendering – Compositing via Ray Casting



## Volume Filtering – Median Filter

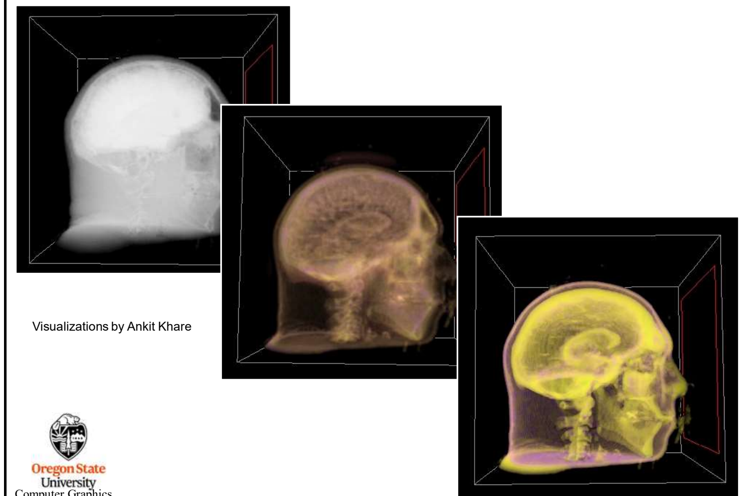


Visualizations by Ankit Khare





## Volume Filtering – High Pass Filter Followed by Median Filter

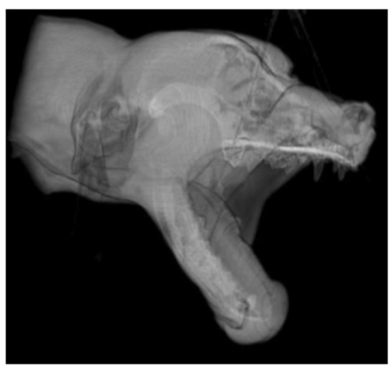


Visualizations by Ankit Khare





## Volume Visualization for OSU'S College of Vet Medicine



Visualization by Chris Schultz



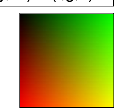


## Vector Visualization: 2D Line Integral Convolution

**At each fragment:**

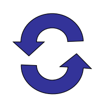
1. **Find the flow field velocity vector there**
2. **Follow that vector in both directions**
3. **Blend in the colors at the other fragments along that vector**

Use a vector field equation, or "hide" the velocity field in another texture image: (vx,vy,vz) ≡ (r,g,b)



**Image**

**+**



**Circular Flow Field**

**=**

## Vector Visualization: 2D Line Integral Convolution



lic2d.frag, I

```
uniform int          uLength;
uniform sampler2D    uImageUnit;
uniform sampler2D    uFlowUnit;
uniform float        uTime;
in vec2              vST;

void
main( )
{
      ivec2 res = textureSize( uImageUnit, 0 );

      // flow field direction:
      vec2 st = vST;
      vec2 v = texture( uFlowUnit, st ).xy;
       v *= 1./vec2(res);.

      st = vST;
      vec3 color = texture( uImageUnit, st ).rgb;
      int count = 1;
```



## Vector Visualization: 2D Line Integral Convolution



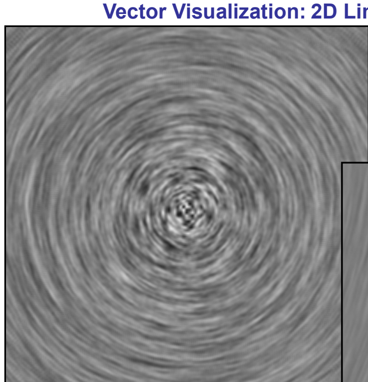
lic2d.frag, II

```
      st = vST;
      for( int i = 0; i < uLength; i++ )
      {
            st += uTime*v;
            vec3 new = texture( uImageUnit, st ).rgb;
            color += new;
            count++;
      }

      st = vST;
      for( int i = 0; i < uLength; i++ )
      {
            st -= uTime*v;
            vec3 new = texture( uImageUnit, st).rgb;
            color += new;
            count++;
      }

      color /= float(count);

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



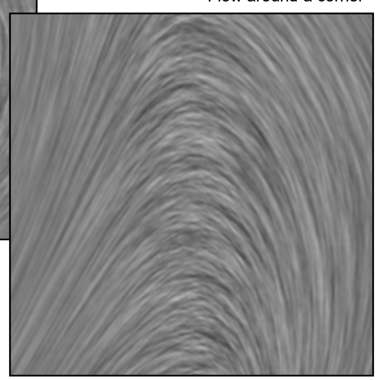
## Vector Visualization: 2D Line Integral Convolution





Flow in a circle

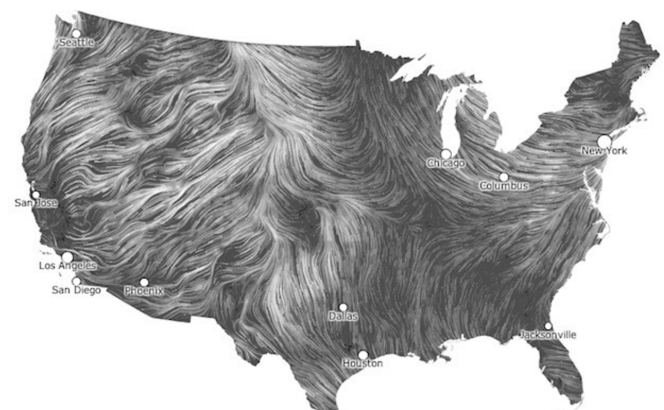
Flow around a corner





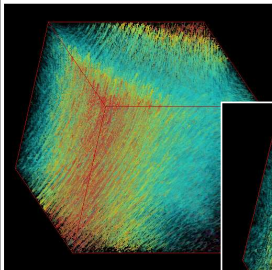
## Vector Visualization: a Cool 2D Line Integral Convolution Example

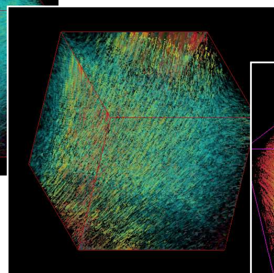




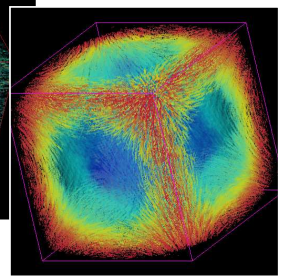

http://hint.fm/wind/

## Vector Visualization: 3D Line Integral Convolution





Visualizations by Vasu Lakshmanan



Oregon State University
Computer Graphics