CS130 : Computer Graphics

Lecture 8: Lighting and Shading (cont.)

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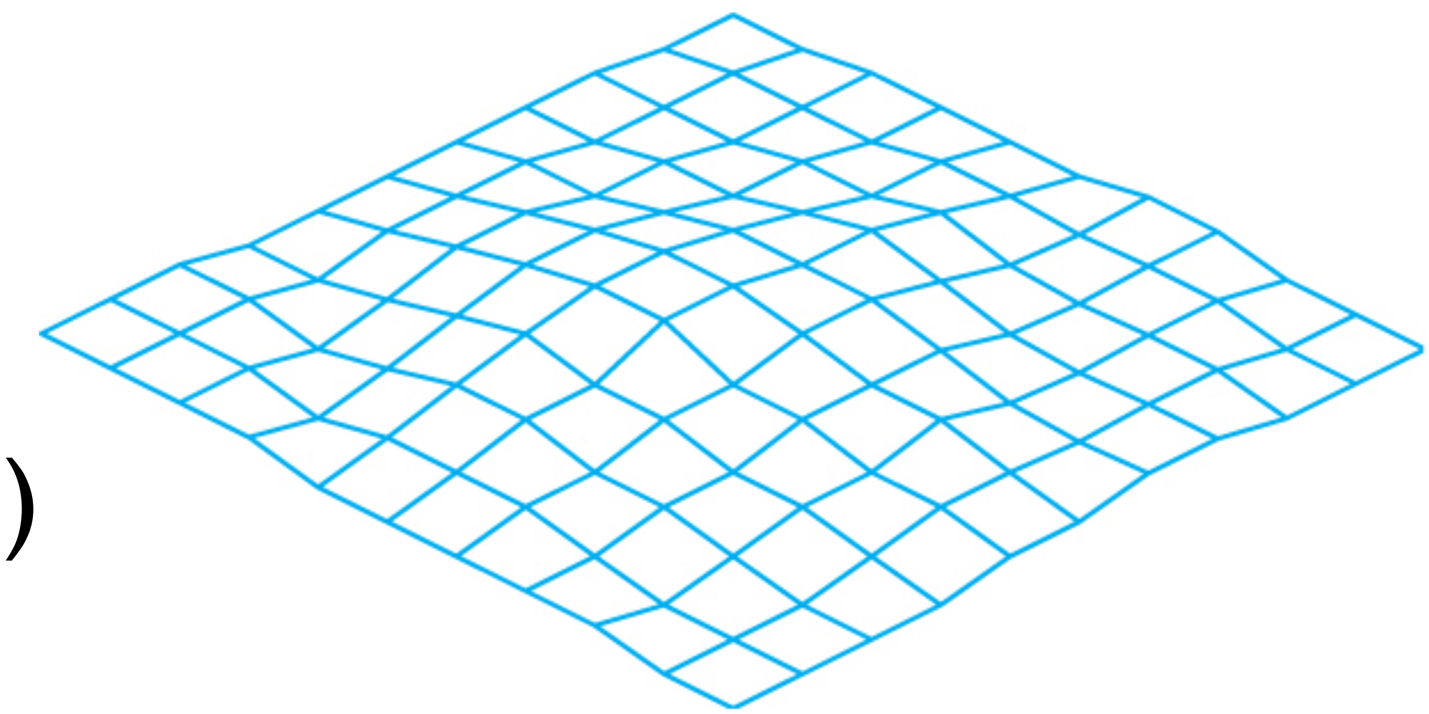
Shading Polygonal Geometry

Smooth surfaces are often approximated by polygons

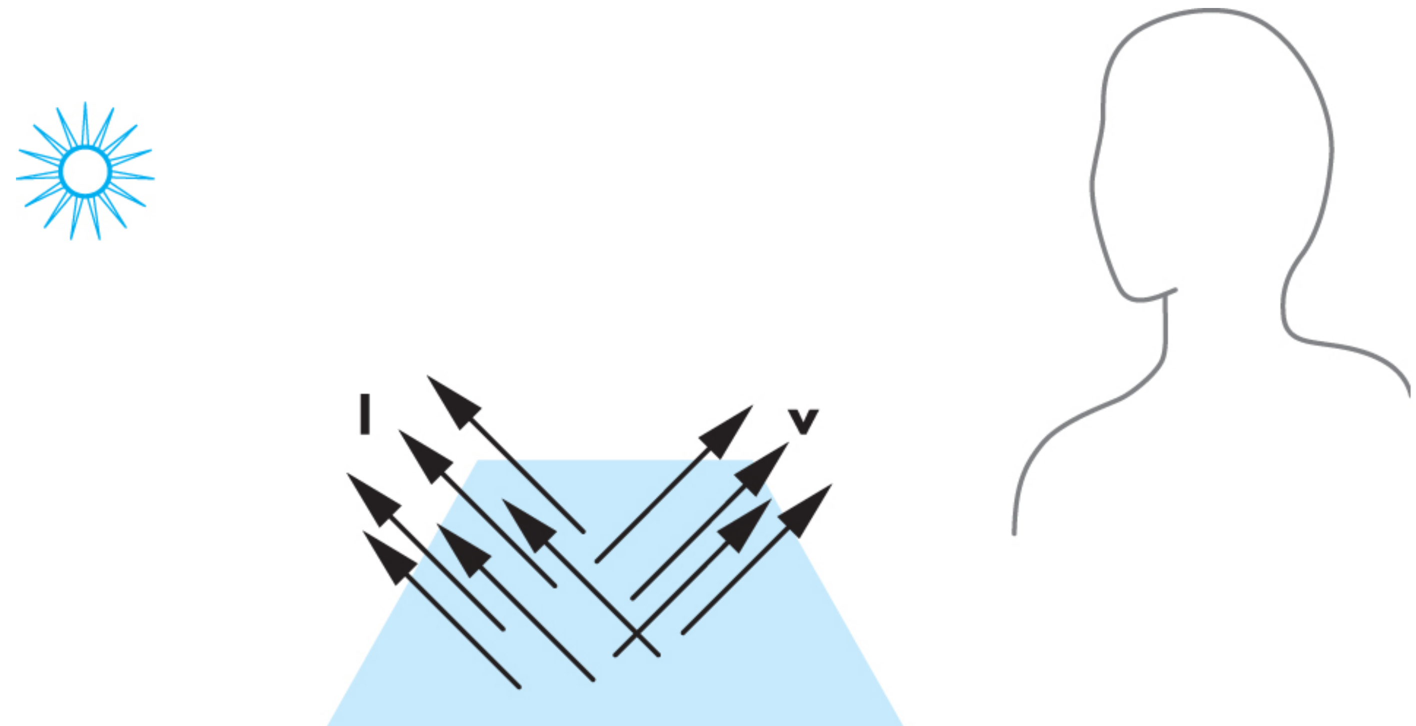
Shading approaches:

1. Flat
2. Smooth (Gouraud)
3. Phong



each polygon is flat and has a well-defined normal

Flat Shading



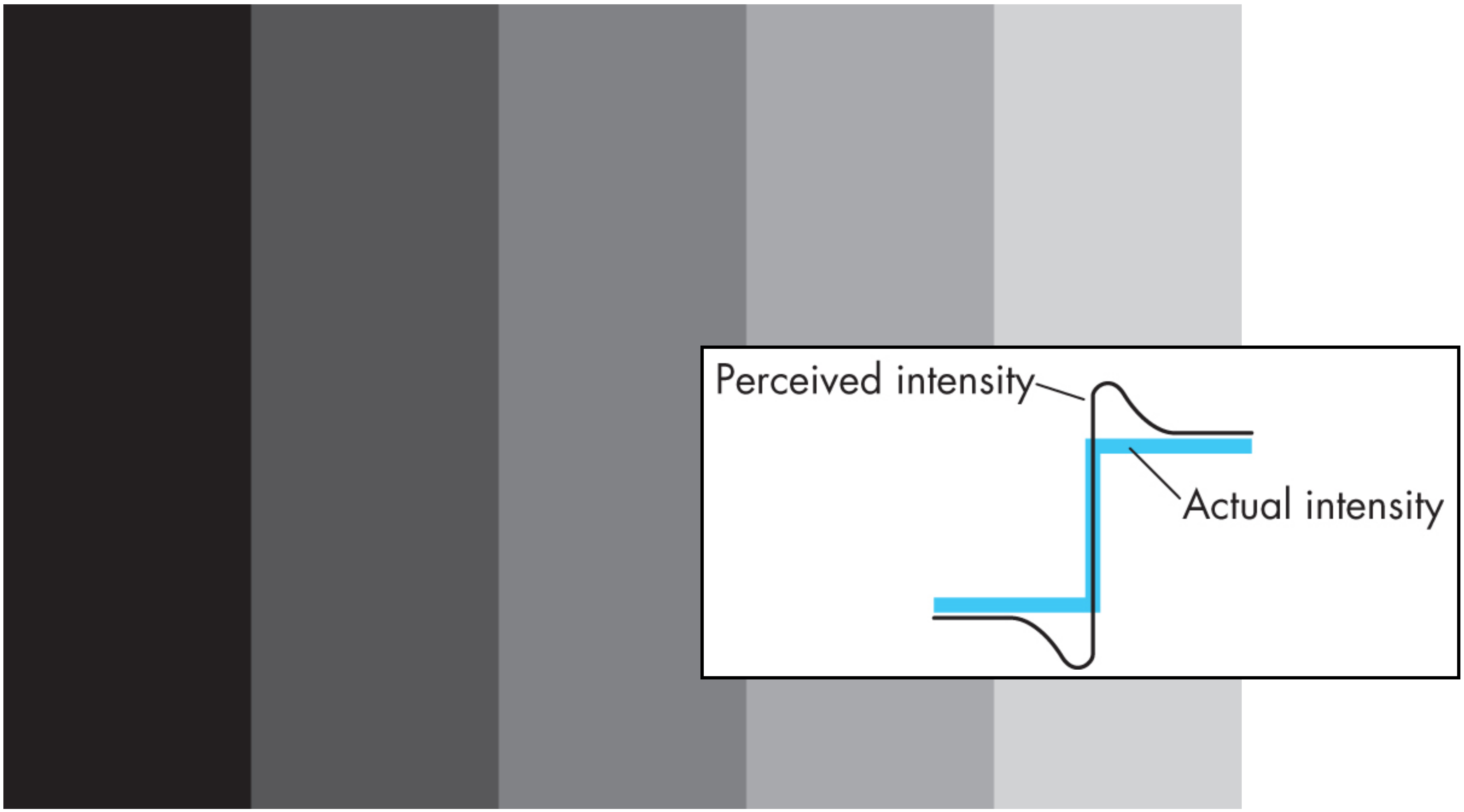
do the shading calculation once per **polygon**

valid for light at ∞ and viewer at ∞ and faceted surfaces

In general, l, n, and v vary from point to point on a surface. If we assume a distant viewer, v can be thought of as constant. If we assume a distant light source, l can be thought of as constant. For a flat polygon, n is constant.

If the light source or viewer is not at inf, we need heuristic for picking color – e.g., first vertex, or polygon center

Mach Band Effect

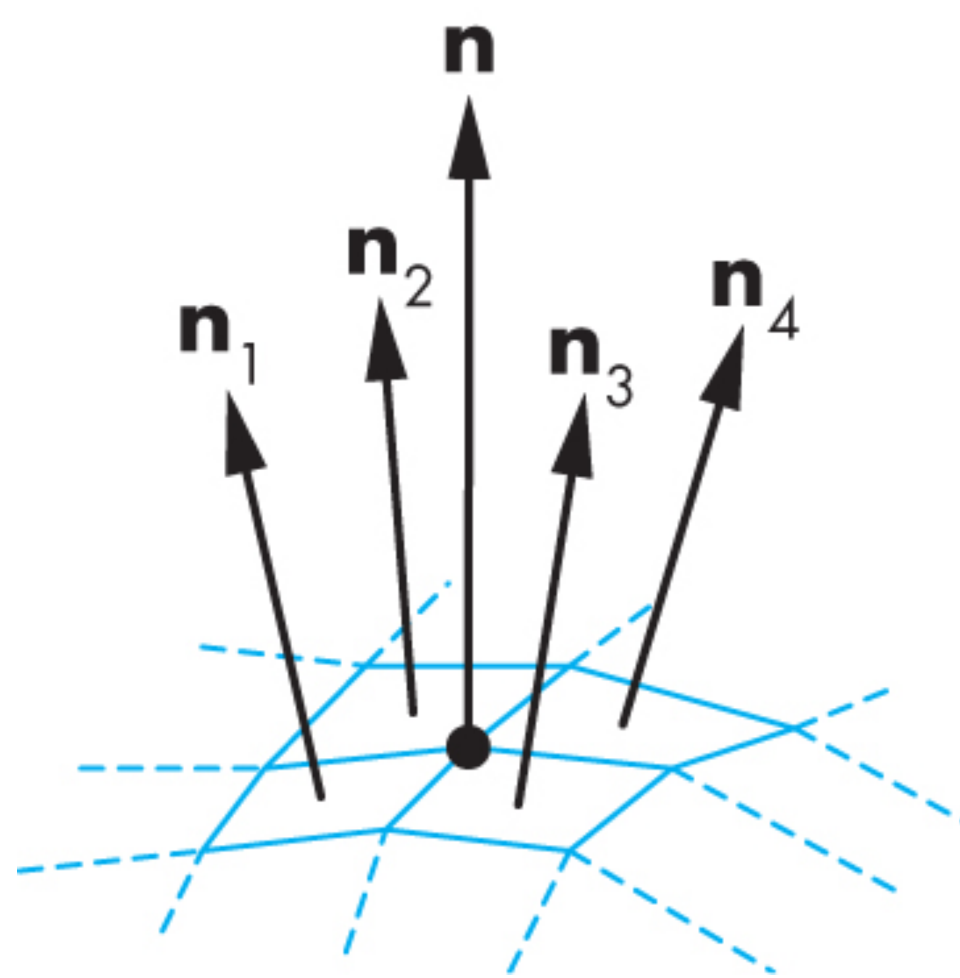


Flat shading doesn't usually look too good.
The **lateral inhibition** effect makes flat shading seem even worse.

Smooth Shading

do the shading calculation once per **vertex**

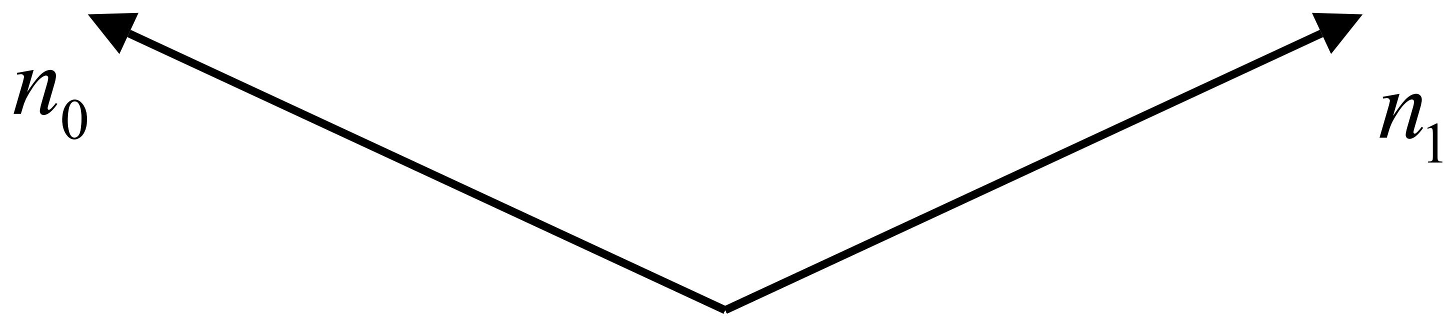
$$\mathbf{n} = \frac{\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4}{||\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4||}$$



We assign the vertex normals based on the surrounding polygon normals

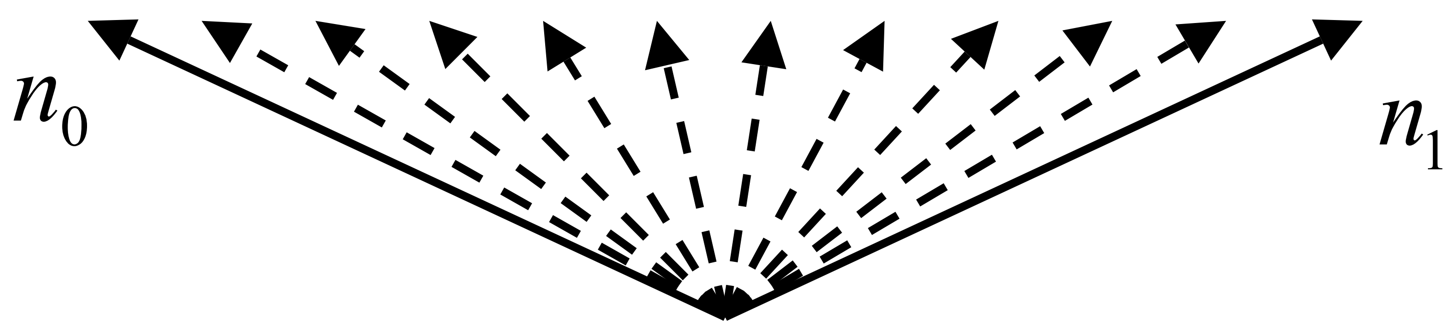
Interpolating Normals

- Must renormalize



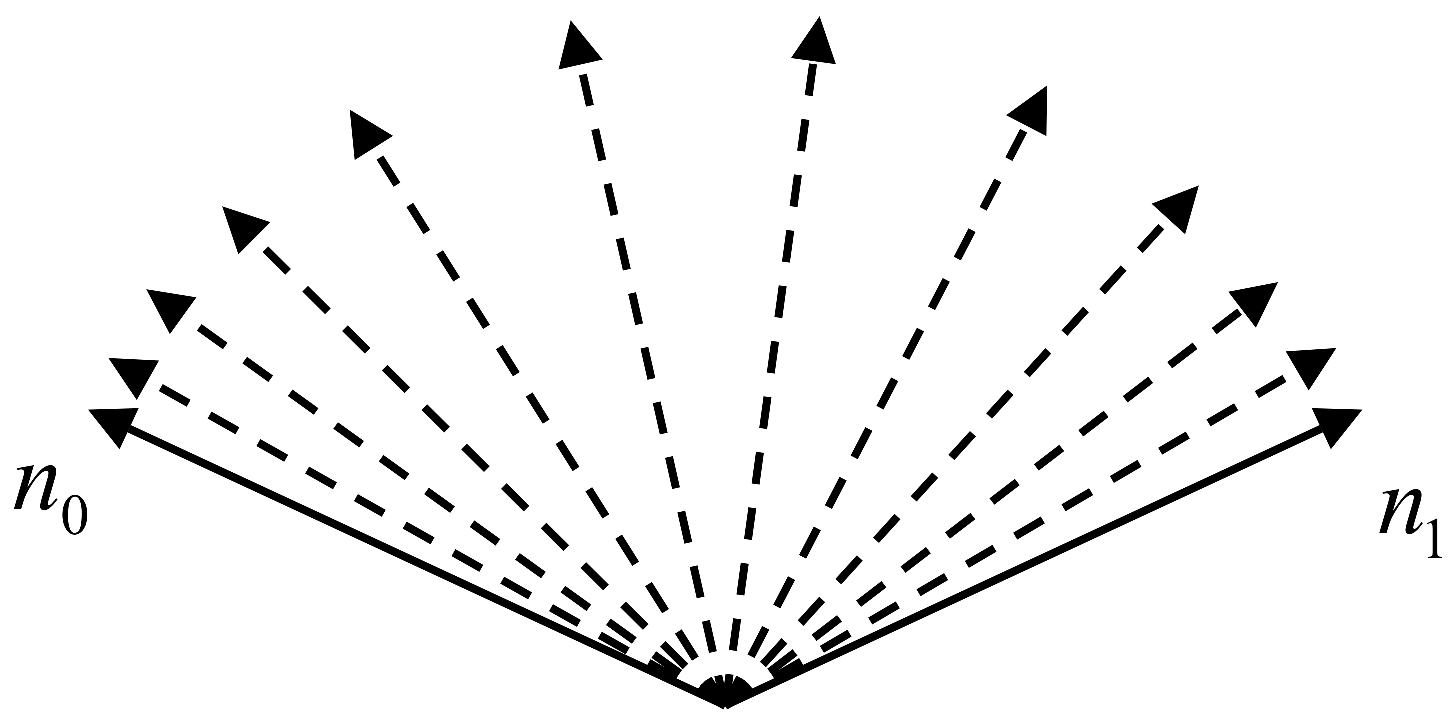
Interpolating Normals

- Must renormalize

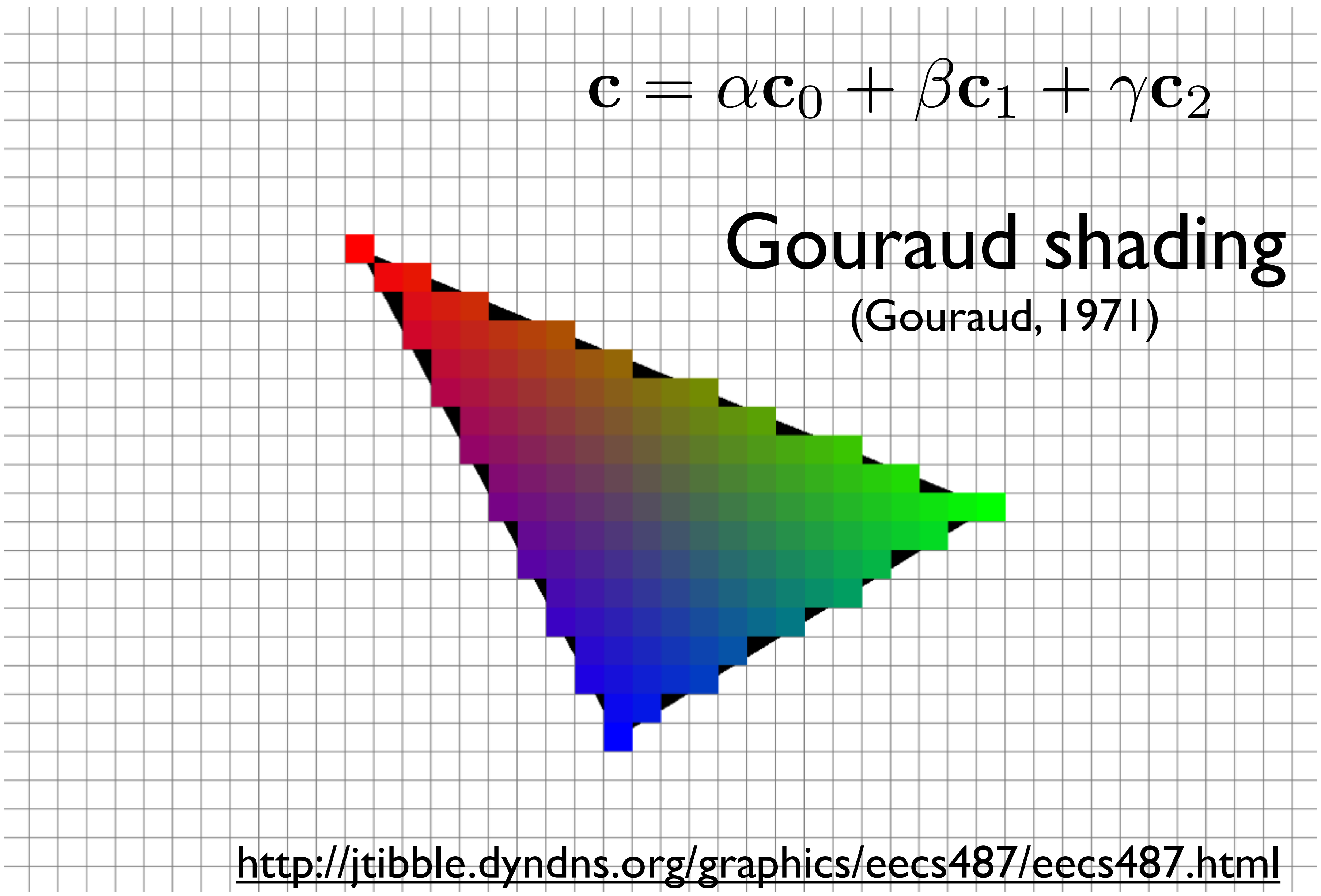


Interpolating Normals

- Must renormalize

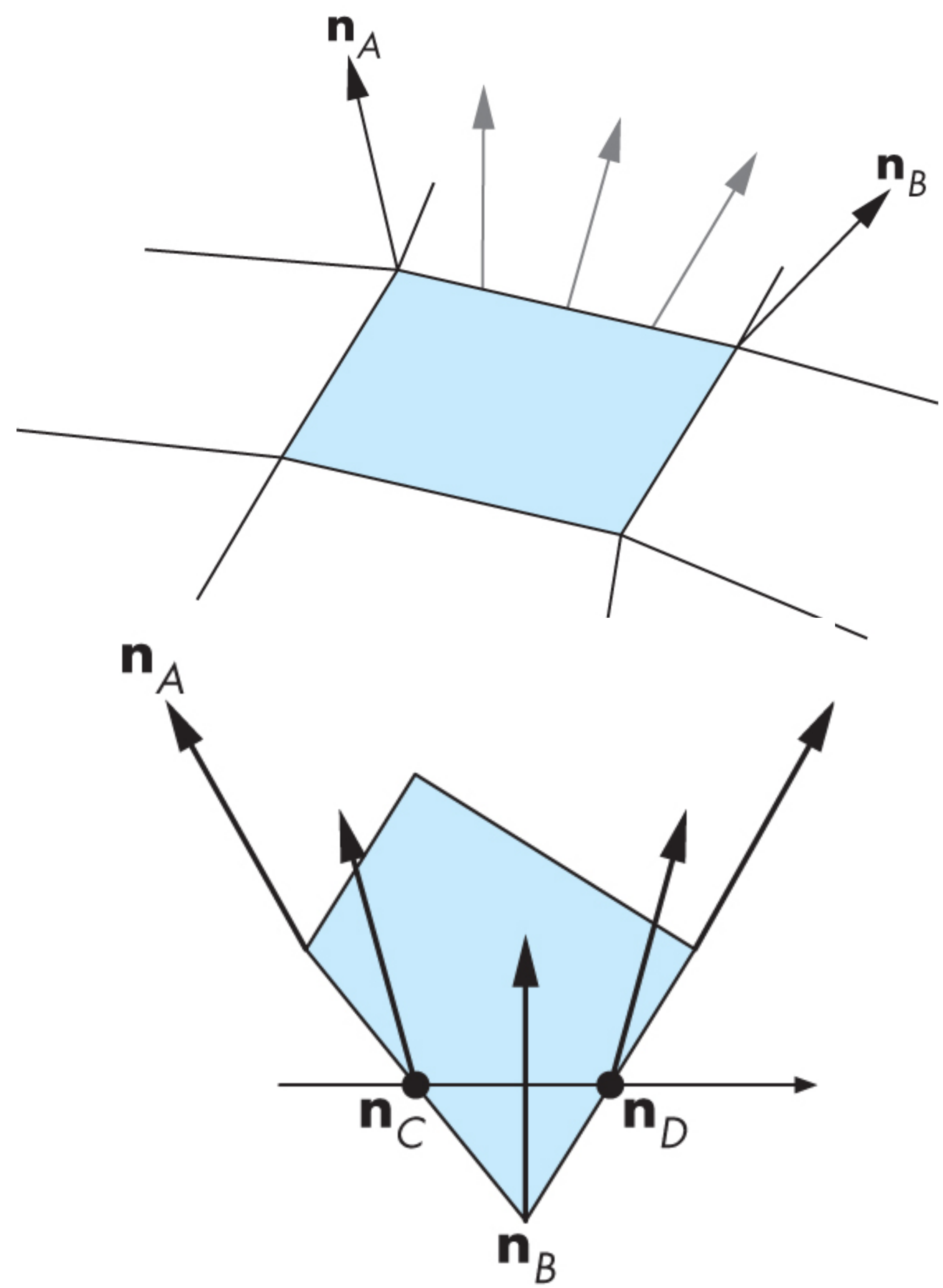


We can interpolate attributes using barycentric coordinates



Using barycentric coordinates also has the advantage that we can easily interpolate colors or other attributes from triangle vertices

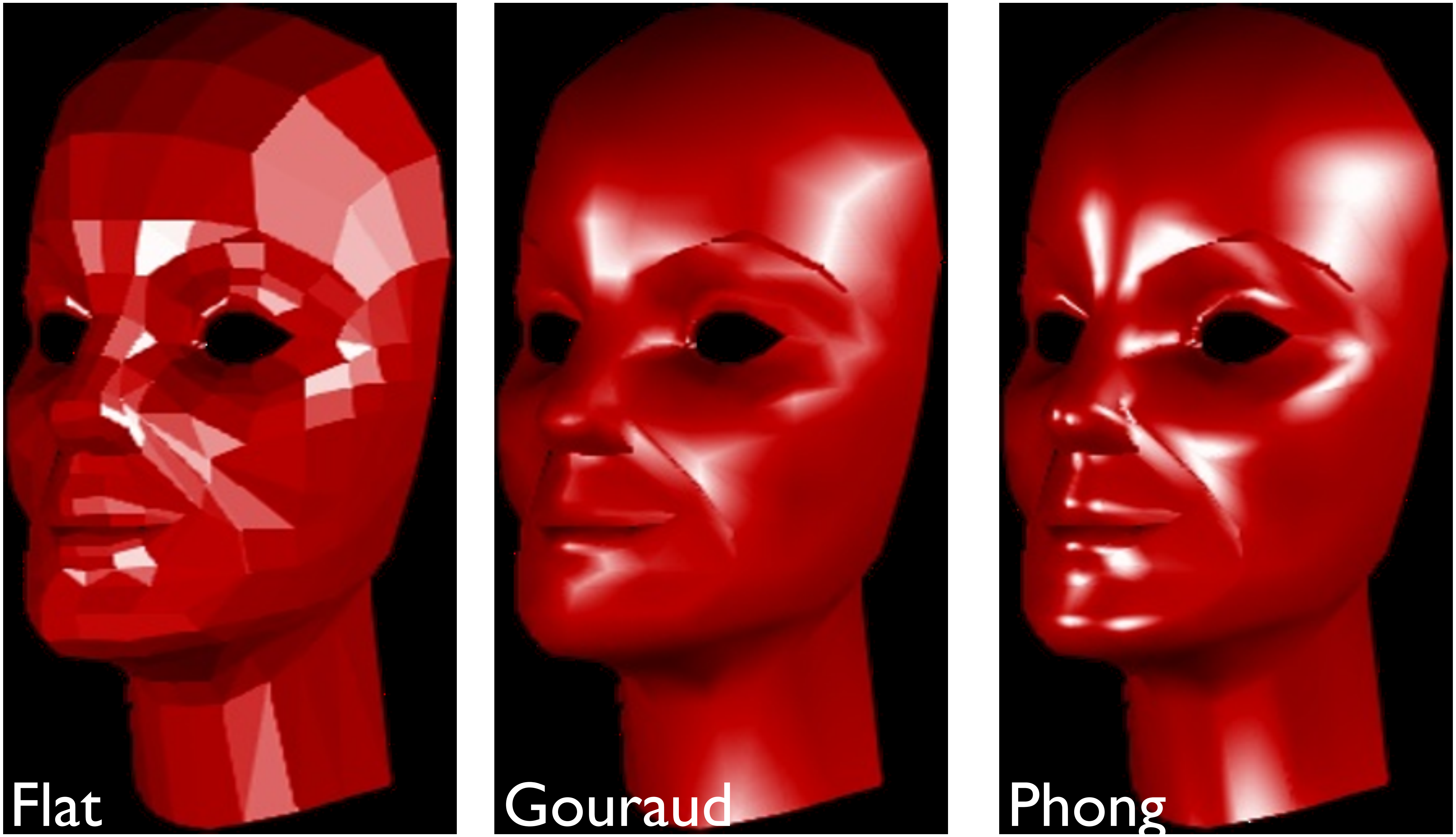
Phong Shading



do the shading calculation once per **fragment**

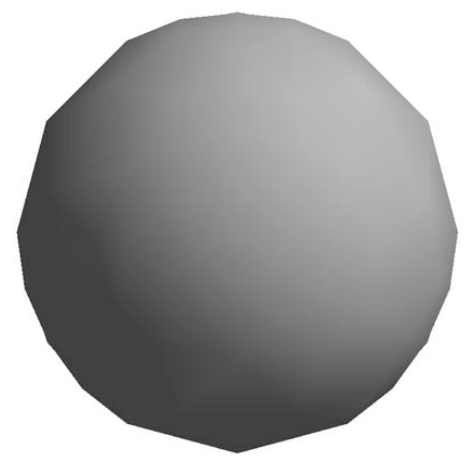
Phong shading requires normals to be interpolated across each polygon -- this wasn't part of the fixed function pipeline.
This can now be done in the pipeline in the fragment shader.

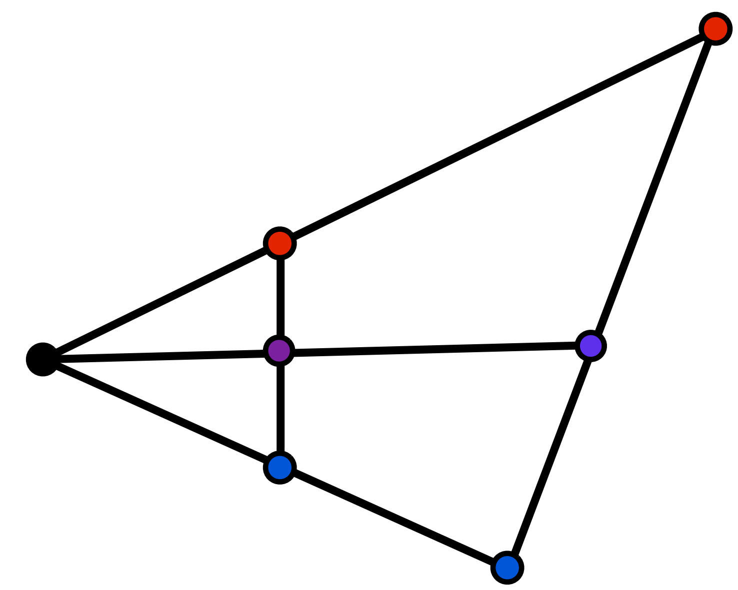
Comparison



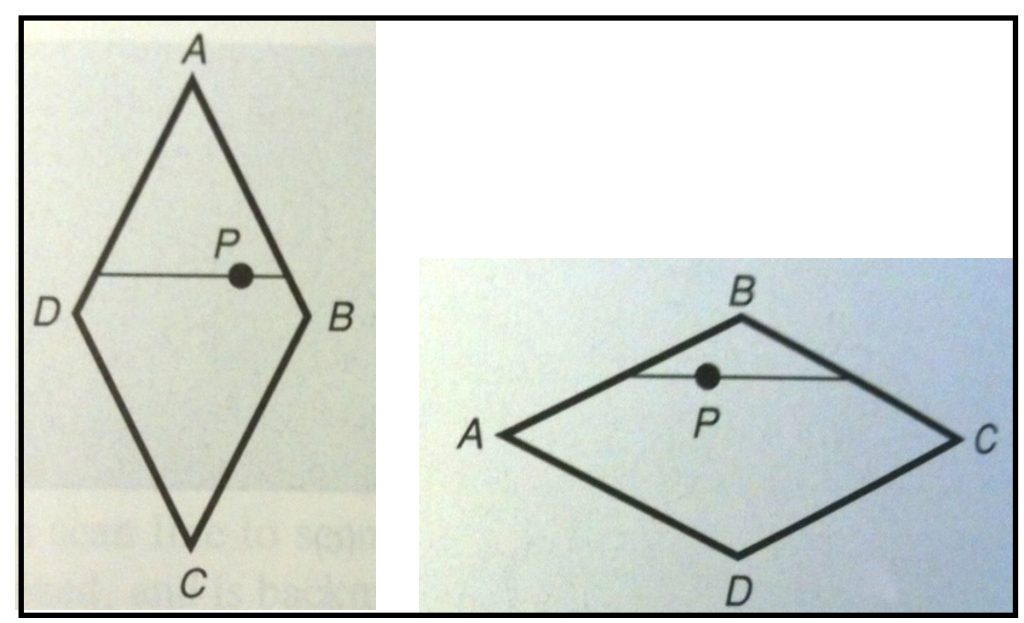
- Phong interpolation looks smoother -- can see edges on the Gouraud model
- but Phong is a lot more work
- both Phong and Gouraud require vertex normals
- both Phong and Gouraud leave silhouettes

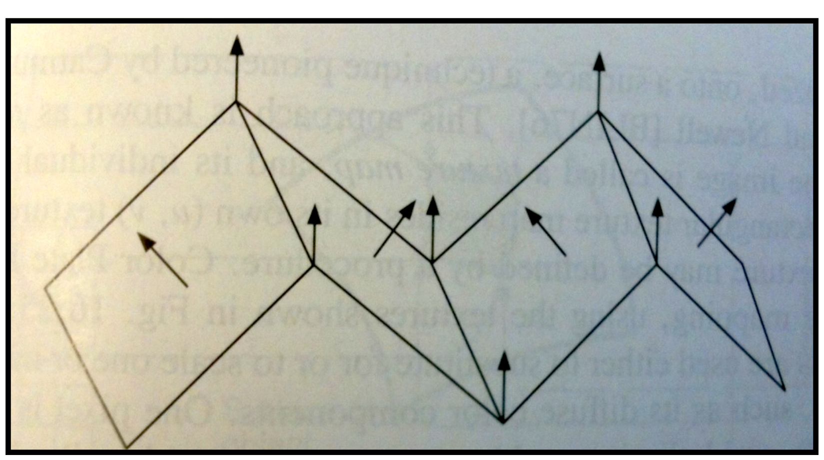
Problems with Interpolated Shading





- Polygonal silhouette
- Perspective distortion
- Orientation dependence
- Unrepresentative surface normals

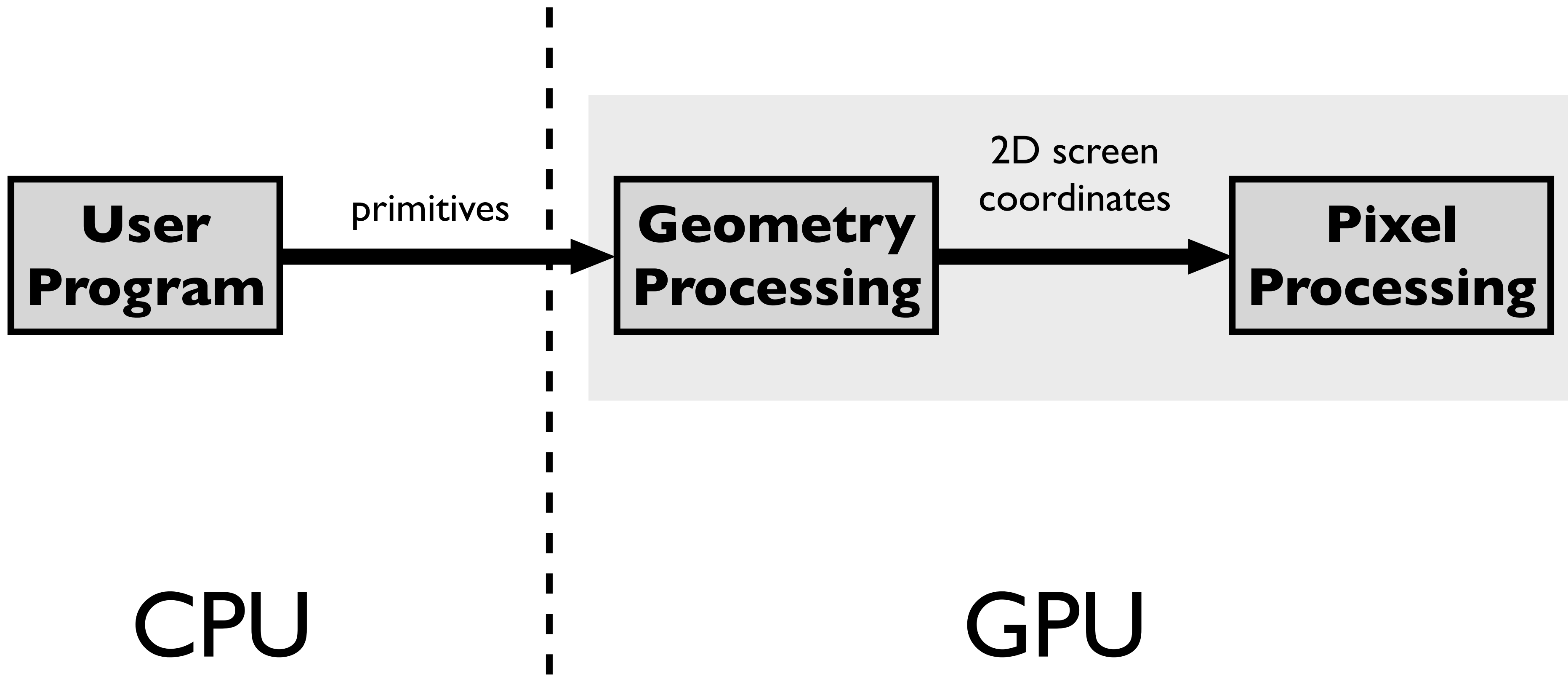




[Foley, van Dam, Feiner, Hughes]

Programmable Shading

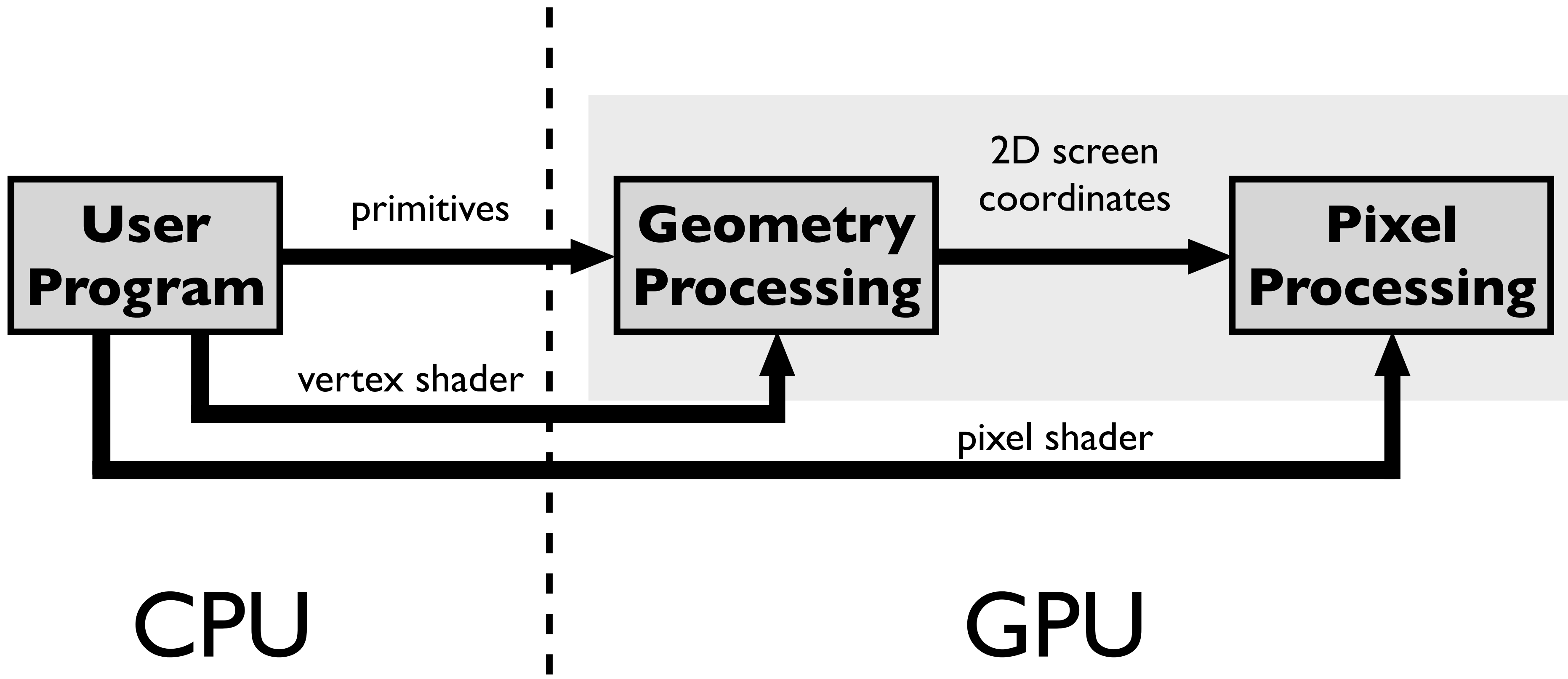
Fixed-Function Pipeline



Control pipeline through GL state variables

- The application supplies geometric primitives through a graphics API such as **OpenGL** or **DirectX**
- control of pipeline operation through state variables only

Programmable Pipeline



Supply shader programs to be executed on GPU as part of pipeline

- can supply shader programs to carry out vertex processing, geometry processing, and pixel processing

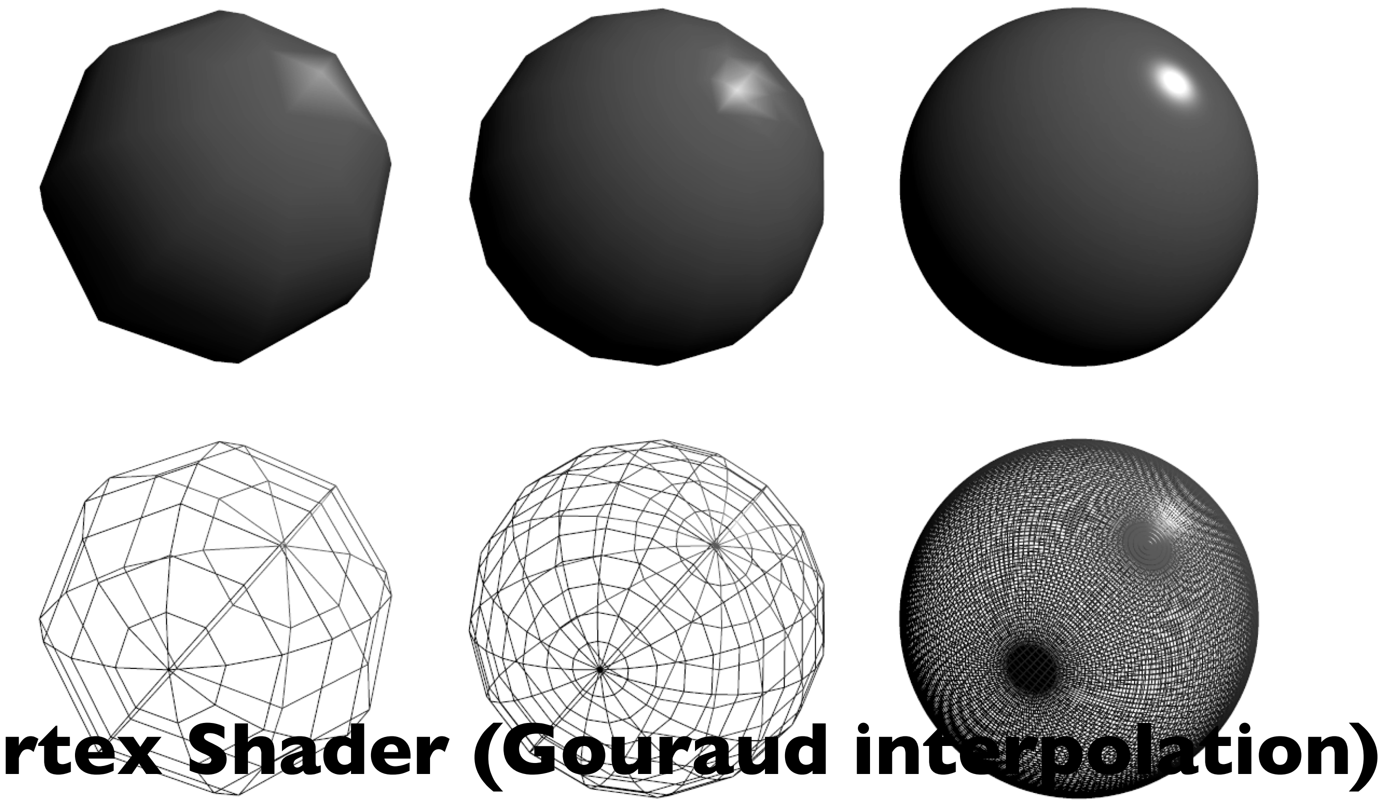
Phong reflectance in vertex and pixel shaders using GLSL

```
void main(void)
{
    vec4 v = gl_modelView_Matrix * gl_Vertex;
    vec3 n = normalize(gl_NormalMatrix * gl_Normal);
    vec3 l = normalize(gl_lightSource[0].position - v);
    vec3 h = normalize(l - normalize(v));

    float p = 16;
    vec4 cr = gl_FrontMaterial.diffuse;
    vec4 cl = fl_LightSource[0].diffuse;
    vec4 ca - vec4(0.2, 0.2, 0.2, 1.0);

    vec4 color;
    if (dot(h,n) > 0)
        color = cr * (ca + cl * max(0,dot(,n,l)))
            + cl* pow(dot(h,n), p);
    else
        color = cr * (ca + cl * max(0,dot(,n,l)));

    gl_FrontColor = color;
    gl_Position = ftransform();
}
```



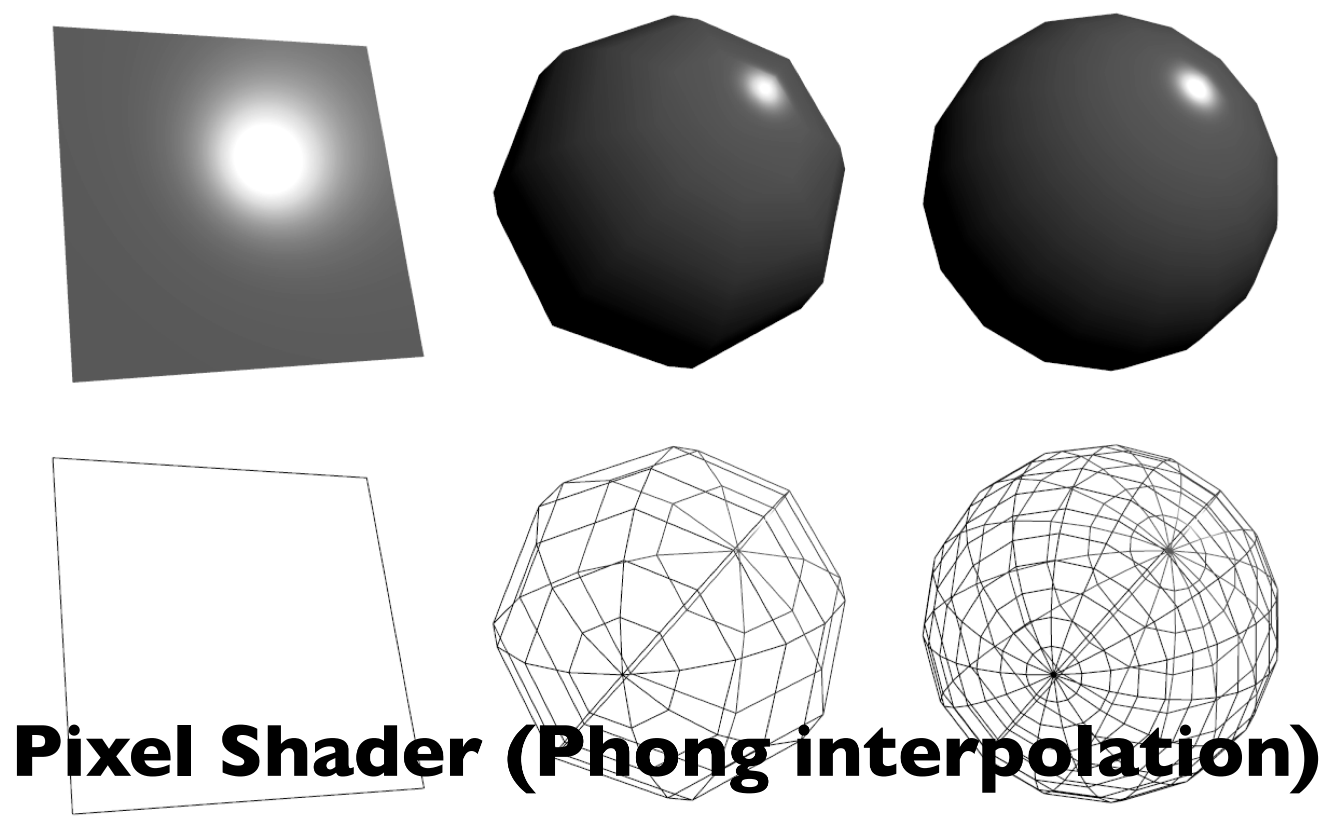

```
varying vec4 v;
varying vec3 n;

void main(void)
{
    vec3 l = normalize(gl_lightSource[0].position - v);
    vec3 h = normalize(l - normalize(v));

    float p = 16;
    vec4 cr = gl_FrontMaterial.diffuse;
    vec4 cl = fl_LightSource[0].diffuse;
    vec4 ca - vec4(0.2, 0.2, 0.2, 1.0);

    vec4 color;
    if (dot(h,n) > 0)
        color = cr * (ca + cl * max(0,dot(,n,l)))
            + cl* pow(dot(h,n), p);
    else
        color = cr * (ca + cl * max(0,dot(,n,l)));

    gl_FragColor = color;
}
```



[Shirley and Marschner]

Phong reflectance as a vertex shader

- vertex shaders can be used to move/animate verts
- linear interpolation of vertex lighting

as a fragment shader

- each fragment is calculated individually - don’t know about neighboring pixles

Rusty car shader, NVIDIA

Call of Juarez DX10 Benchmark, ATI

Dawn, NVIDIA

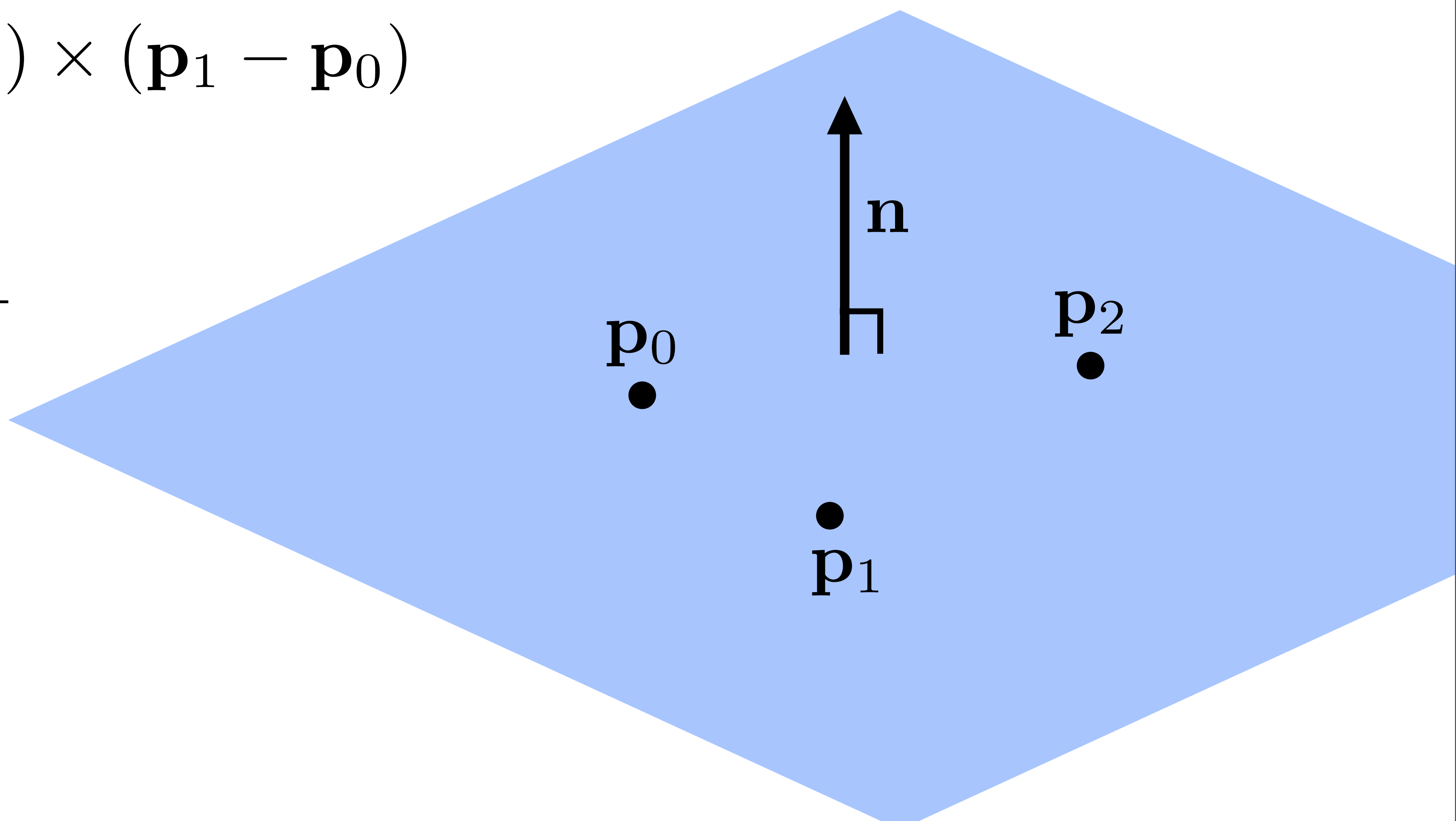
Programmable shader examples from NVIDIA and ATI

Computing Normal Vectors

Plane Normals

$$\mathbf{v} = (\mathbf{p}_2 - \mathbf{p}_0) \times (\mathbf{p}_1 - \mathbf{p}_0)$$

$$\mathbf{n} = \frac{\mathbf{v}}{||\mathbf{v}||}$$



Implicit function normals

$$f(\mathbf{p}) = 0$$

$$\nabla f(\mathbf{p})$$

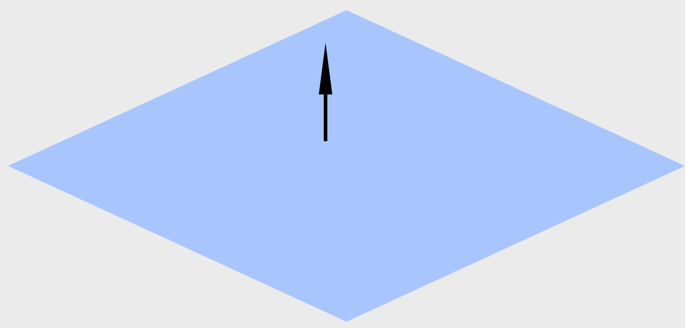
$$\nabla f = \begin{pmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \\ \frac{\partial f}{\partial z} \end{pmatrix}$$

sphere

$$\mathbf{p} \cdot \mathbf{p} - r^2 = 0$$

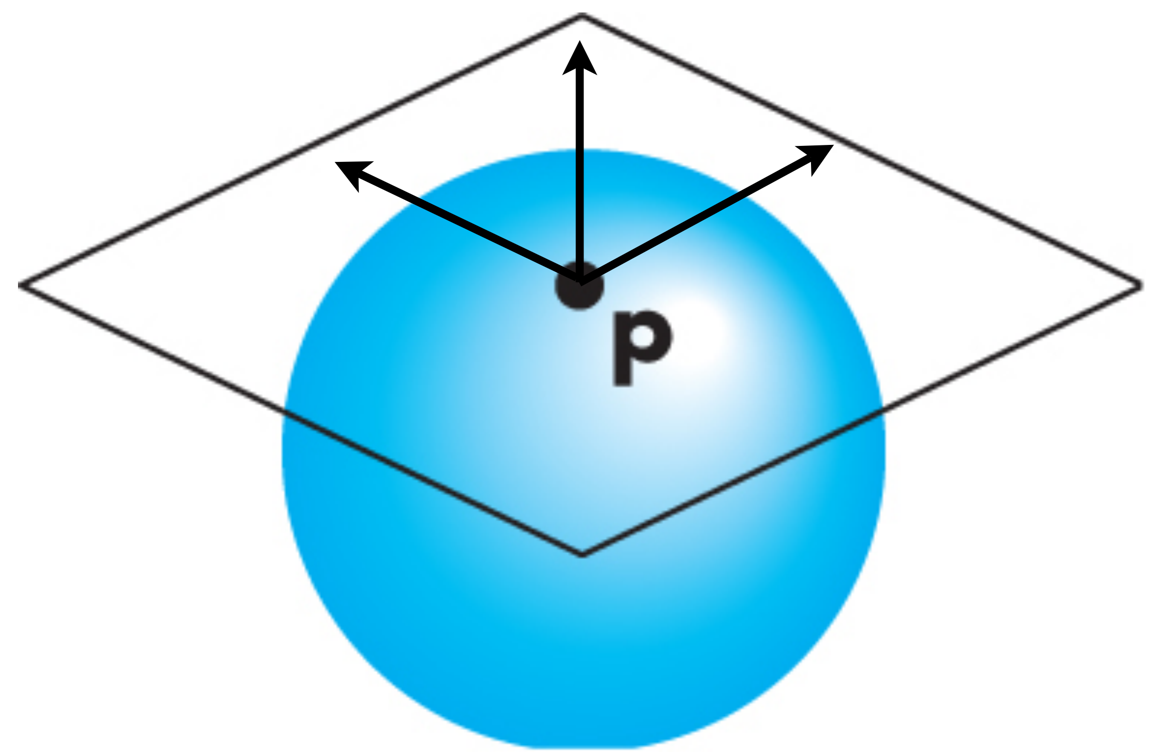
plane

$$\mathbf{n} \cdot (\mathbf{p} - \mathbf{p}_0) = 0$$



Parametric form

$$\mathbf{p}(u,v) = \begin{pmatrix} x(u,v) \\ y(u,v) \\ z(u,v) \end{pmatrix}$$



tangent vectors $\quad \dfrac{\partial \mathbf{p}}{\partial u} \quad \dfrac{\partial \mathbf{p}}{\partial v}$

normal $\quad \dfrac{\frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v}}{||\frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v}||}$

Texture Mapping

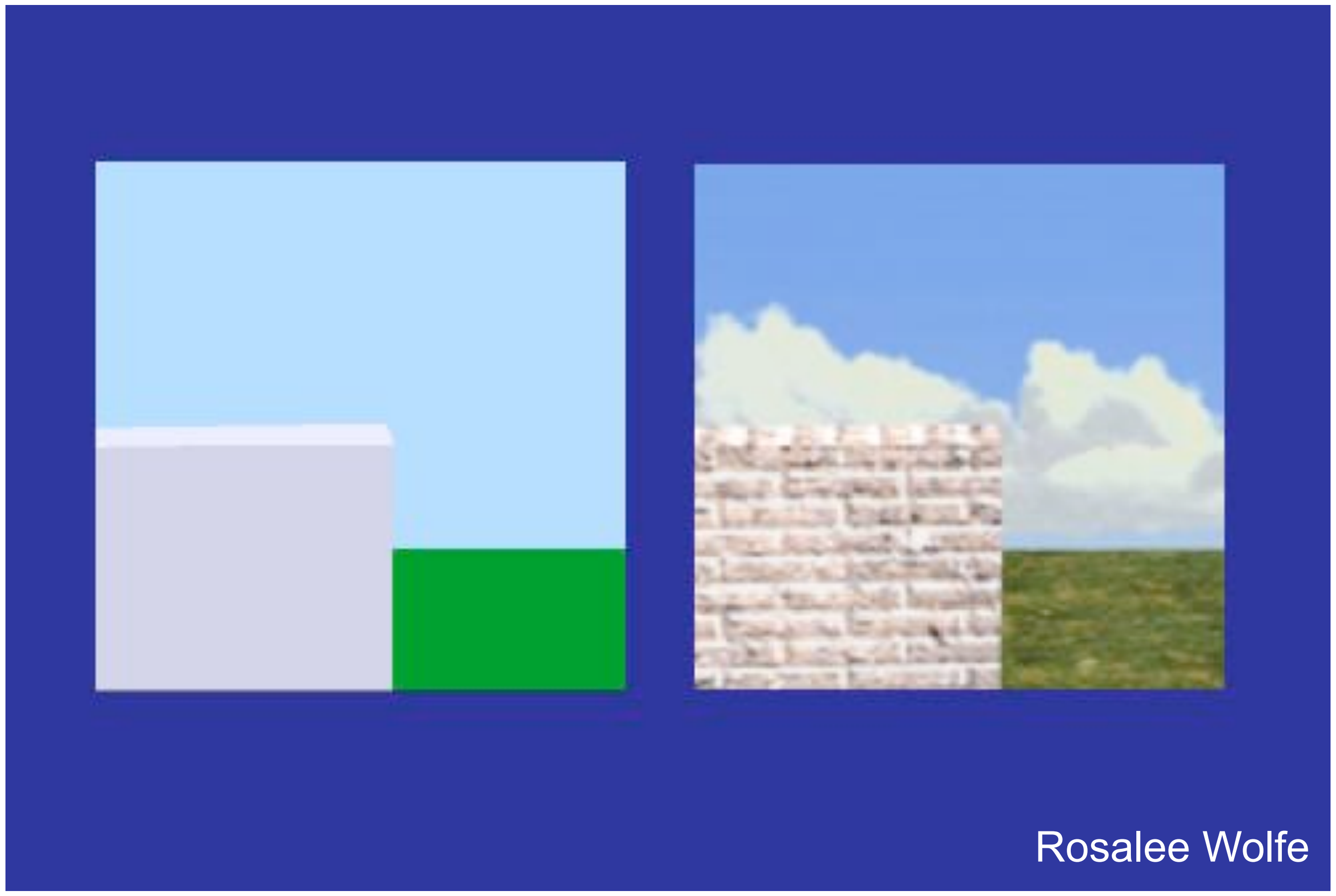
There are limits to geometric modeling

http://www.beinteriordecorator.com

National Geographic

Although modern GPUs can render millions of triangles/sec, that's not enough sometimes...

Use texture mapping to increase realism through detail

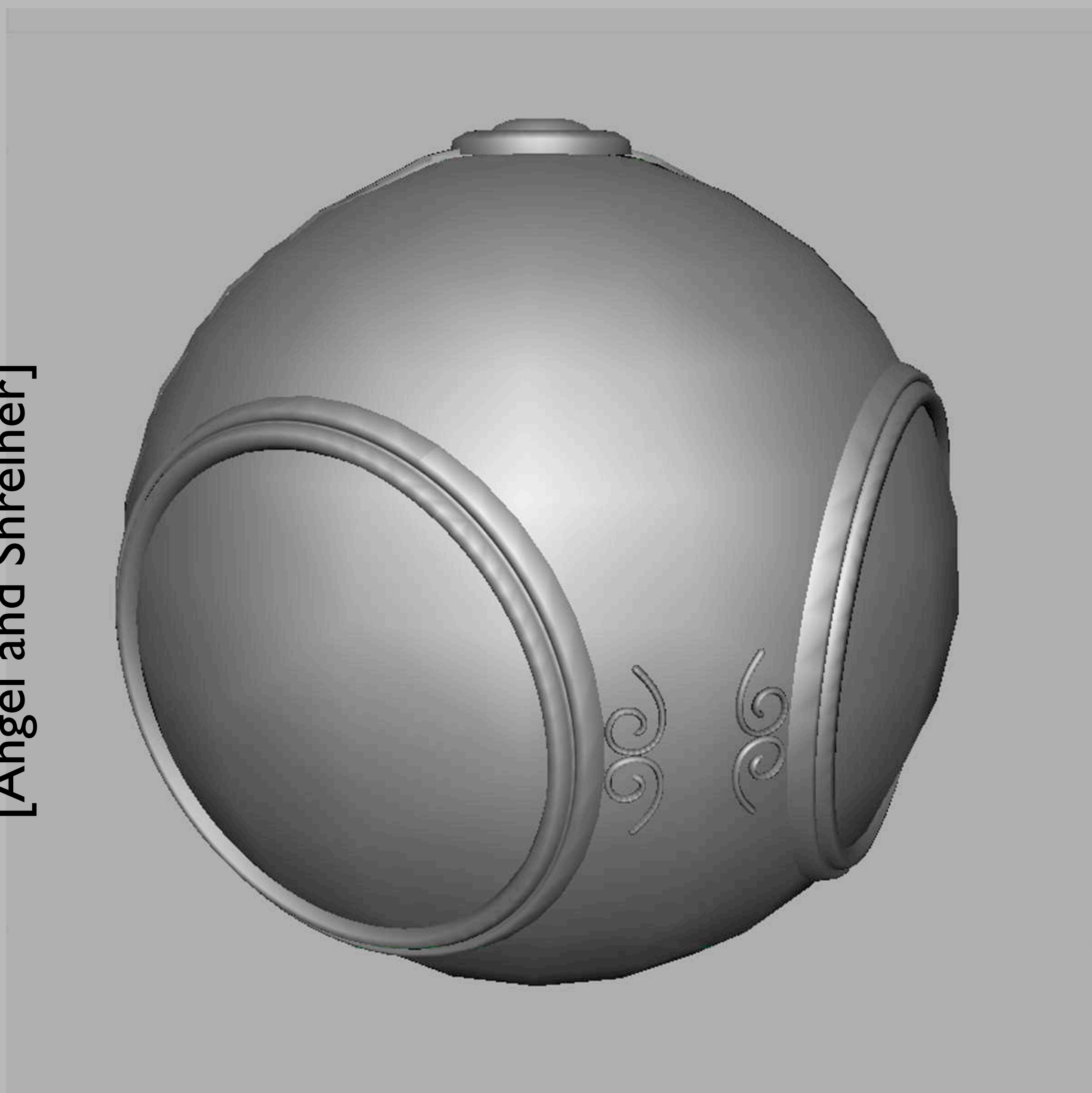


This image is just 8 polygons!

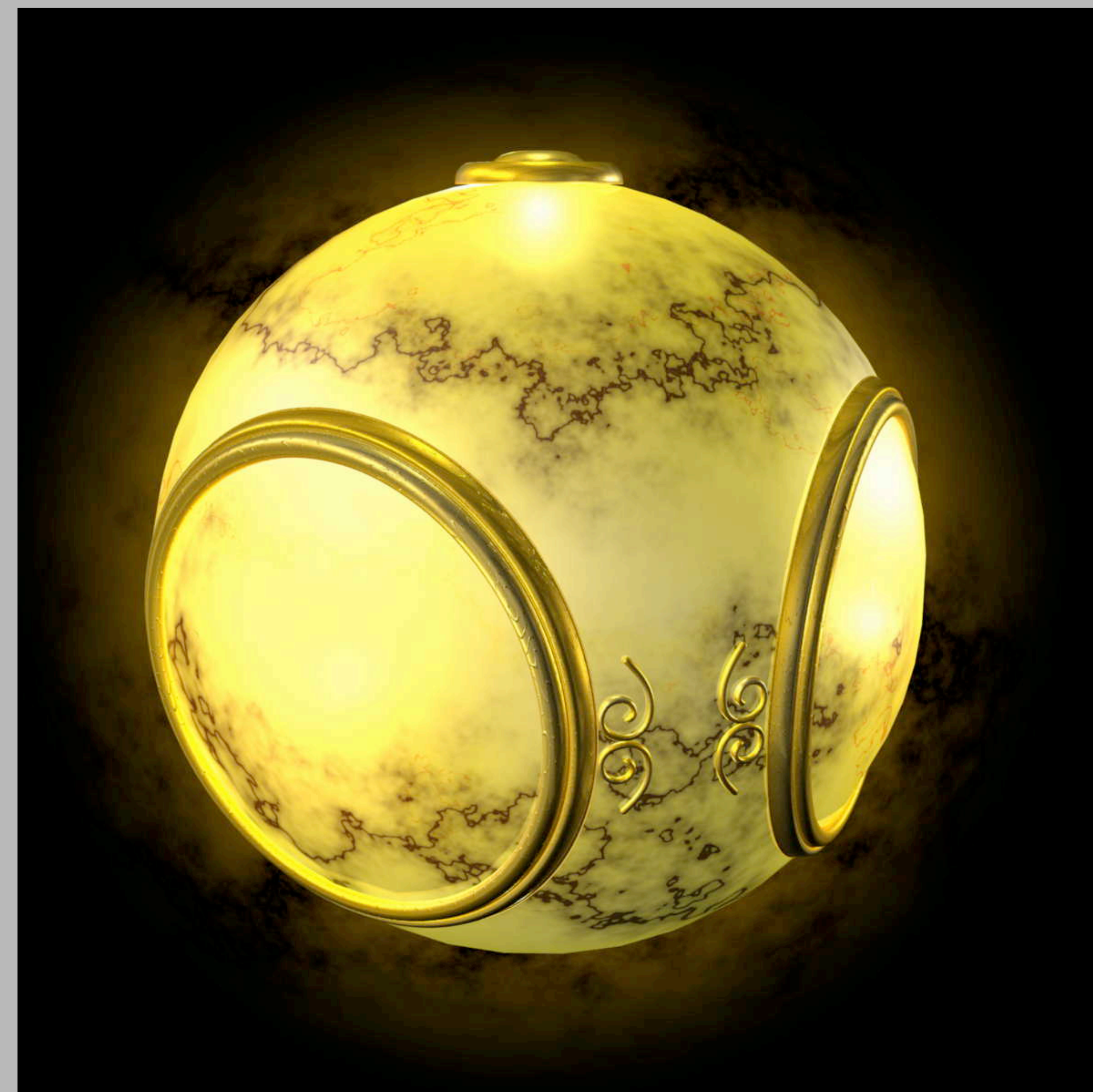
Add visual complexity.

http://www.siggraph.org/education/materials/HyperGraph/mapping/r_wolfe/r_wolfe_mapping_1.htm

[Angel and Shreiner]



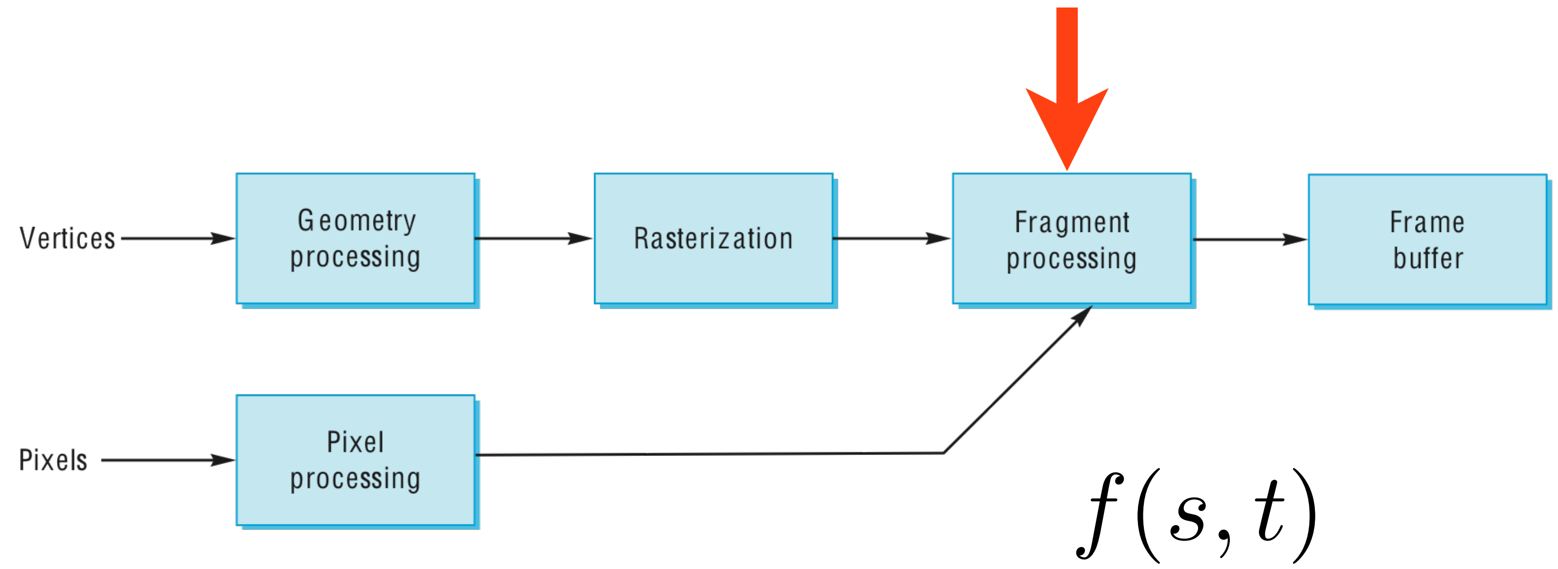
No texture

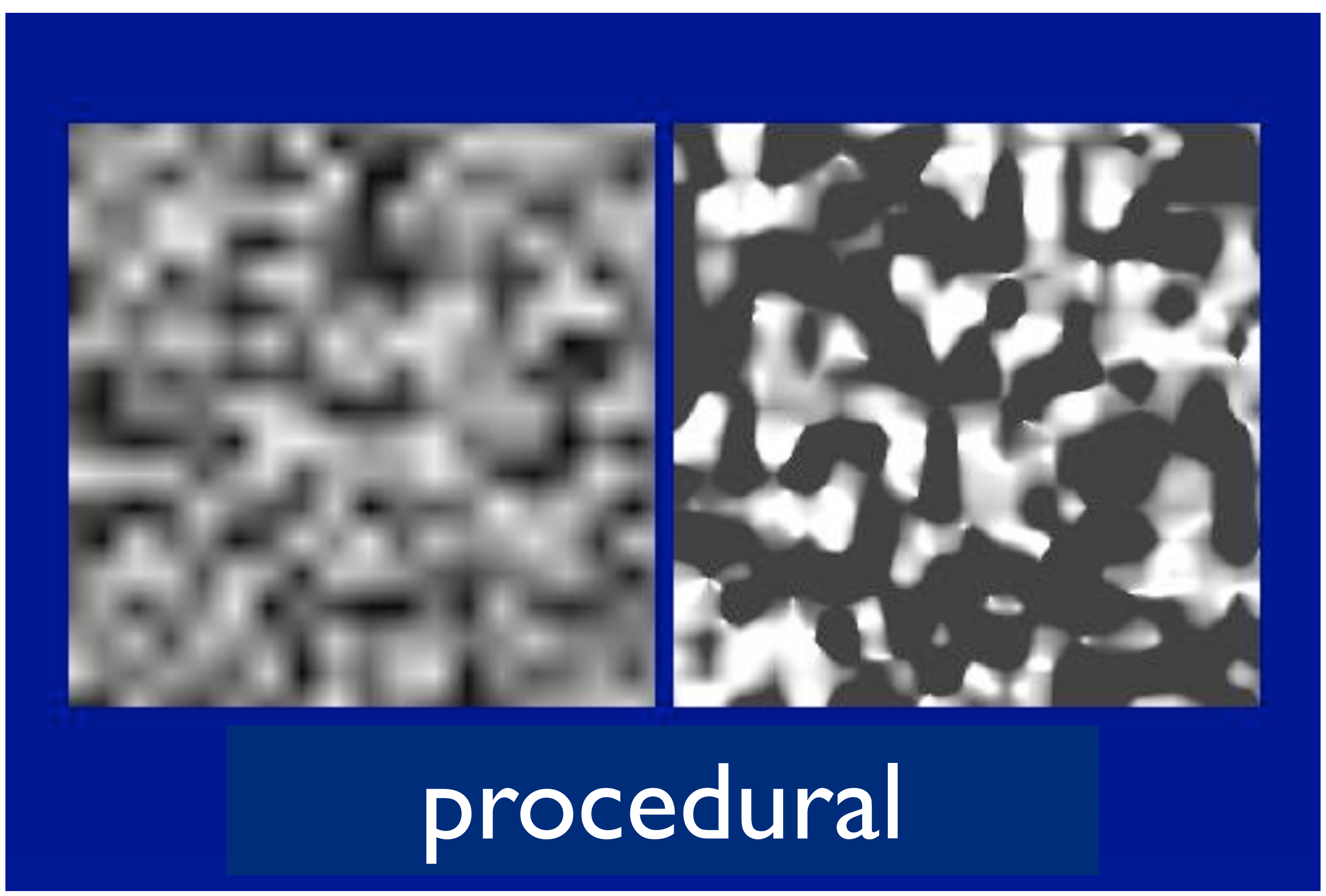


With texture

Pixar - Toy Story

Store 2D images in buffers and lookup pixel reflectances





photo

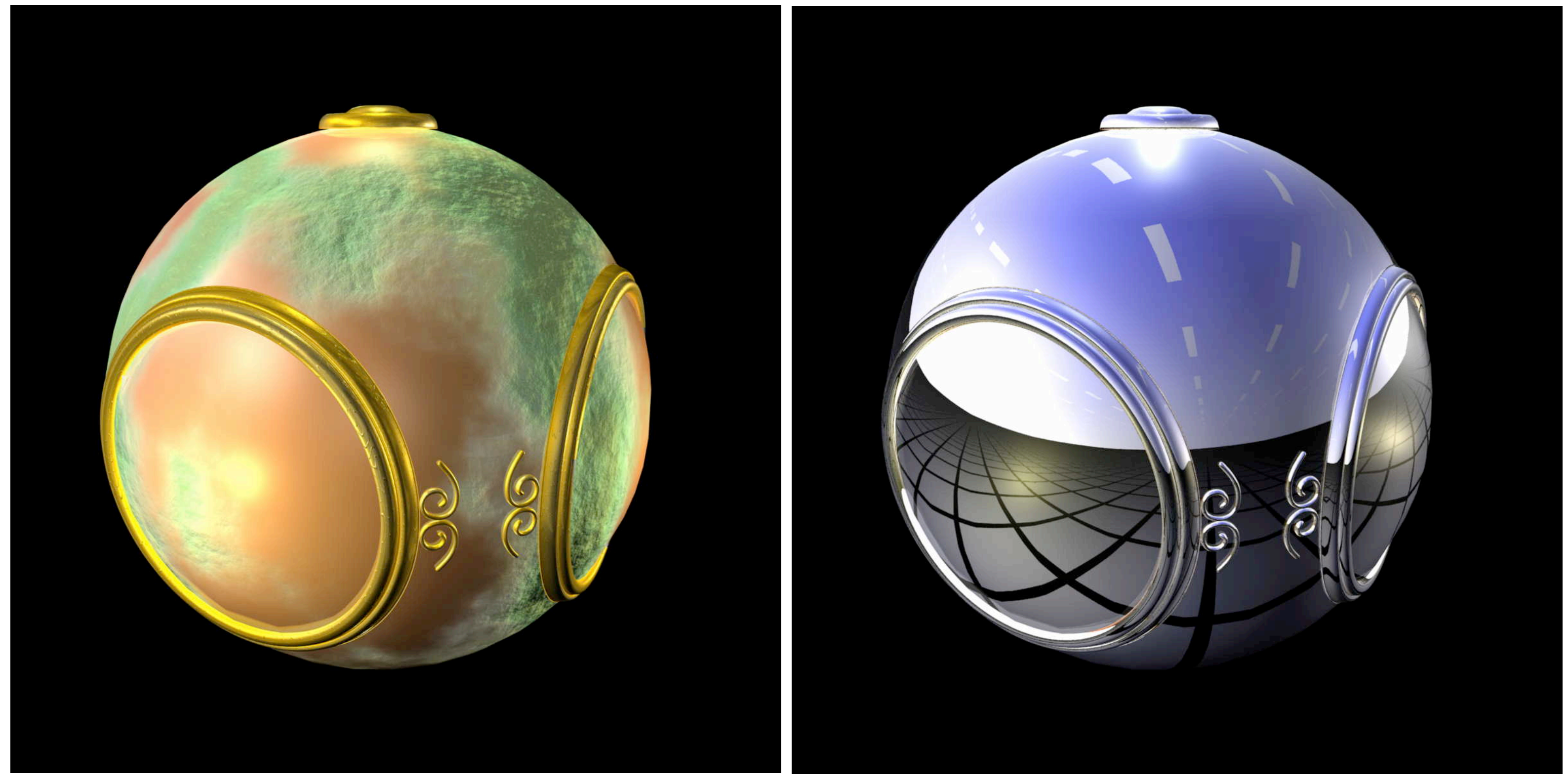
Textures can be anything that you can lookup values in -- photo, procedurally generated, or even a function that computes a value on the fly

3D solid textures

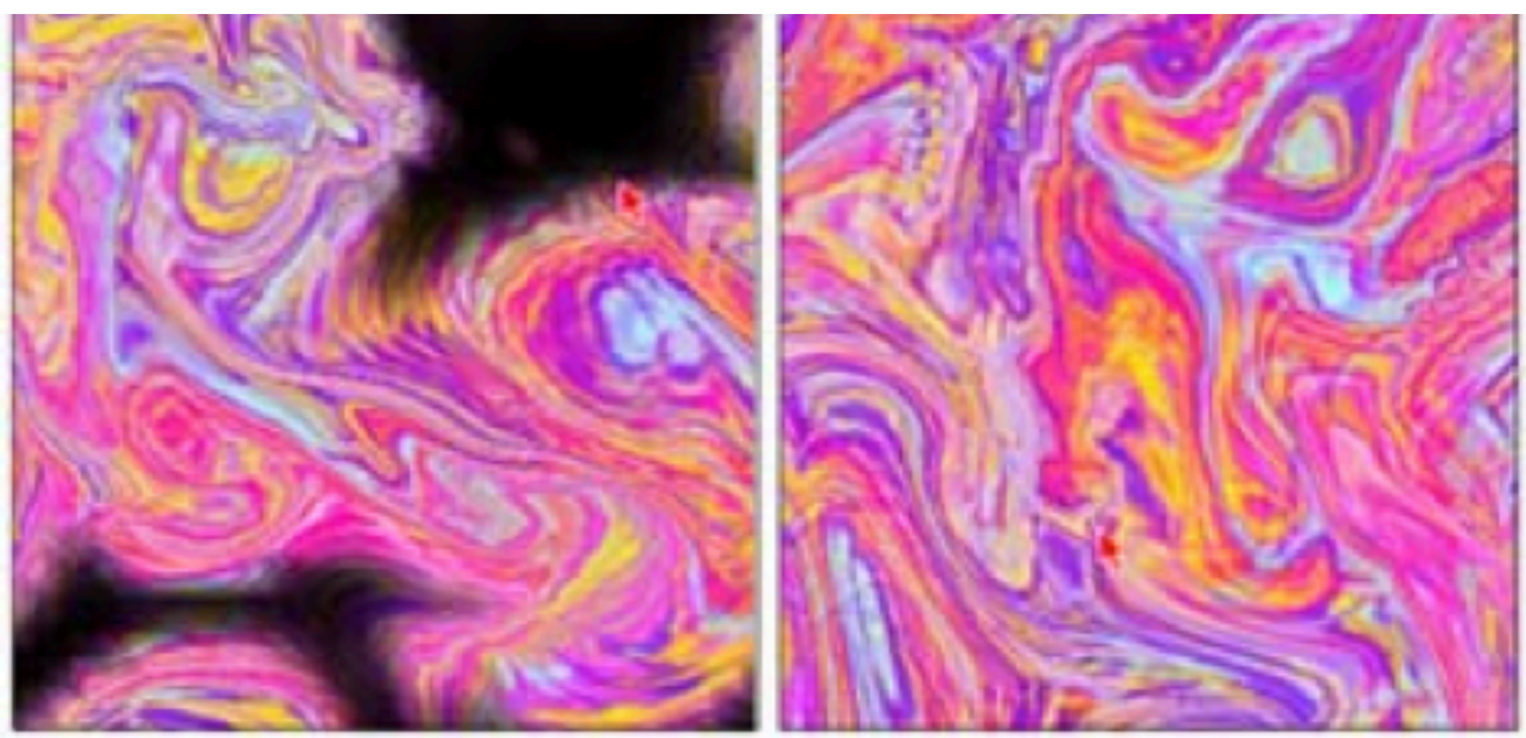
[Dong et al., 2008]

Other uses of textures...

Light maps
Shadow maps
Environment maps
Bump maps
Opacity maps
Animation

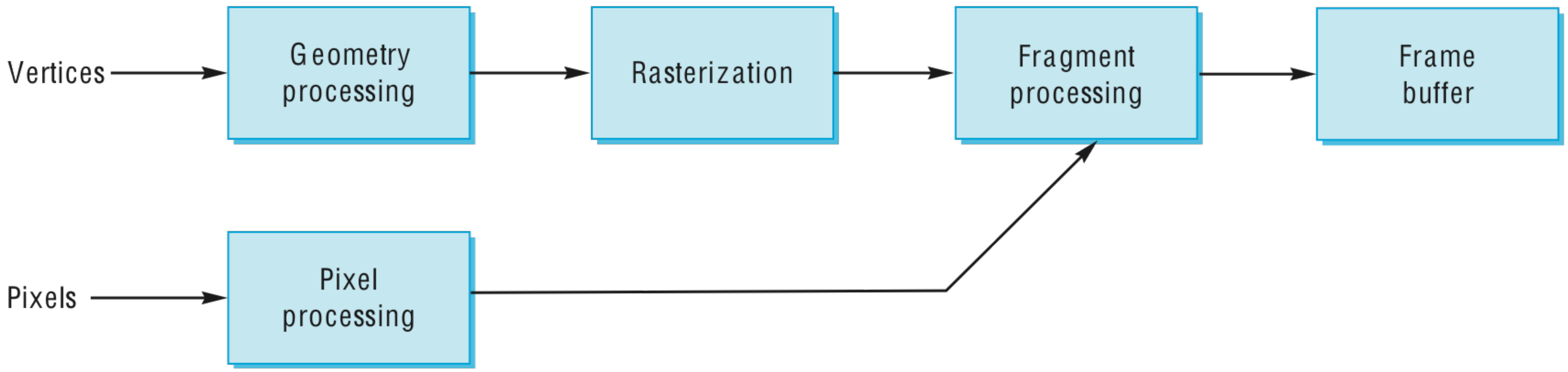


[Angel and Shreiner]



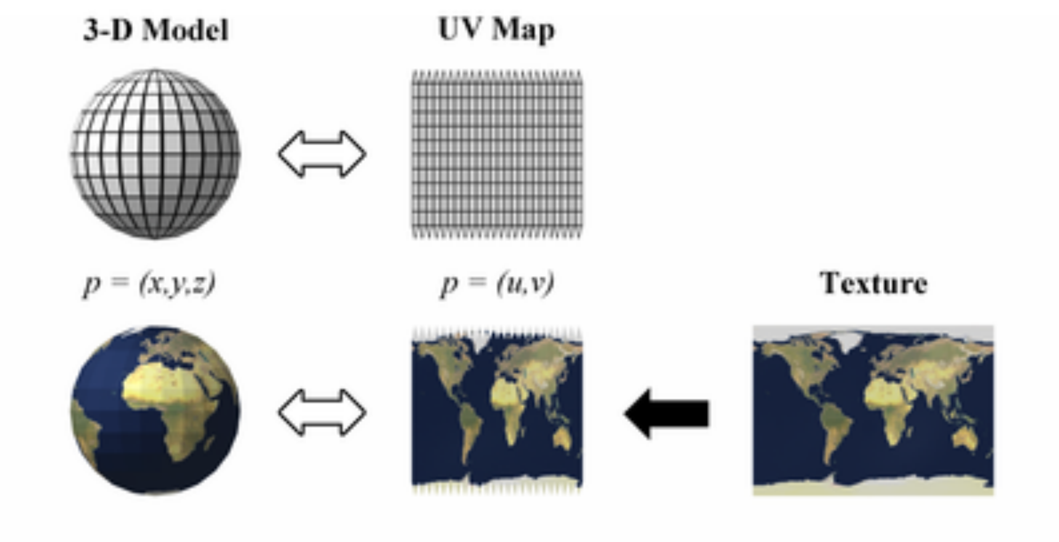
[Stam 99]

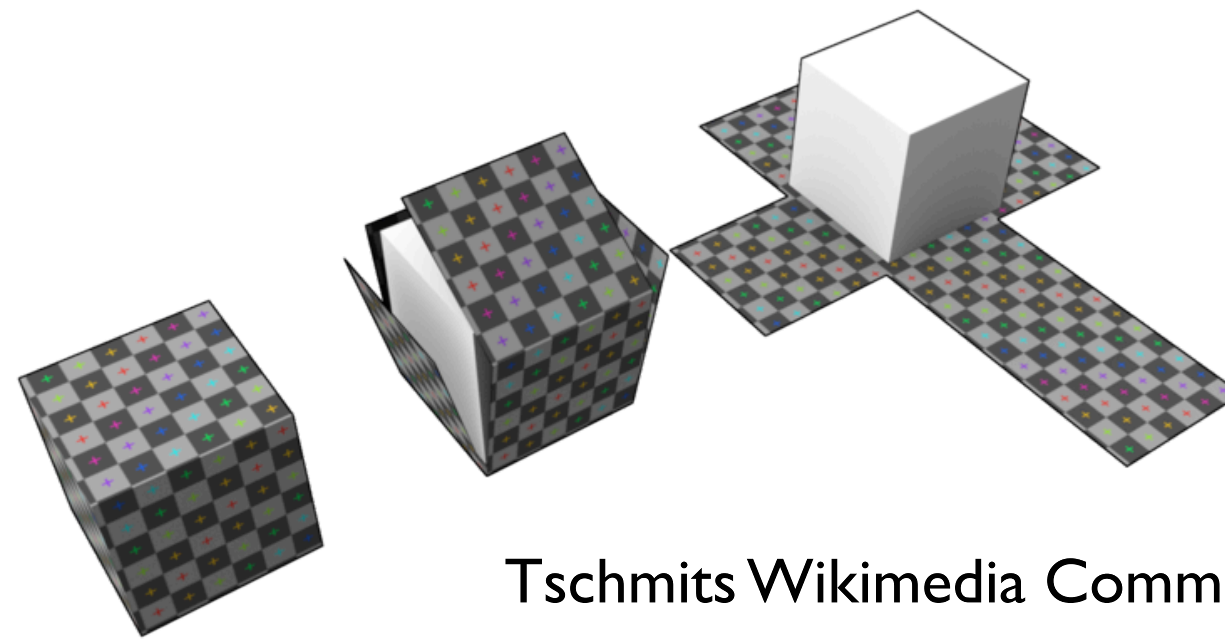
Texture mapping in the OpenGL pipeline



- Geometry and pixels have separate paths through pipeline
- meet in **fragment processing** - where textures are applied
- texture mapping applied at end of pipeline - efficient since relatively few polygons get past clipper

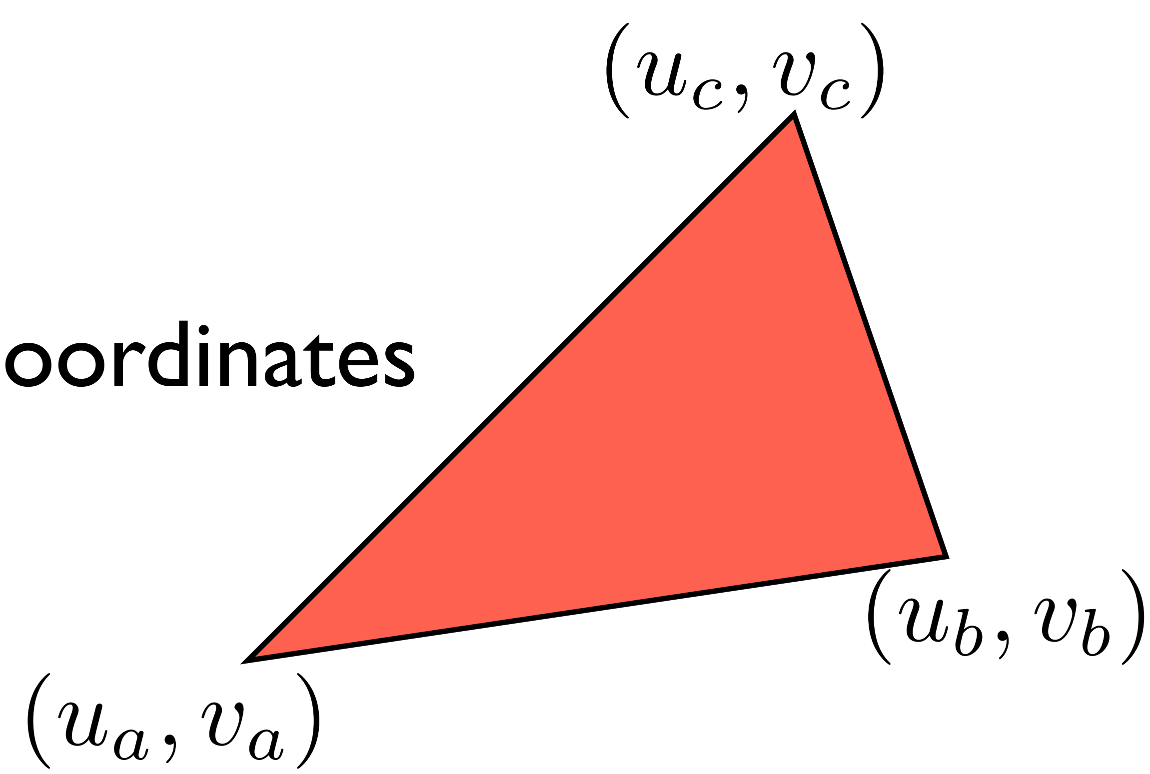
uv Mapping



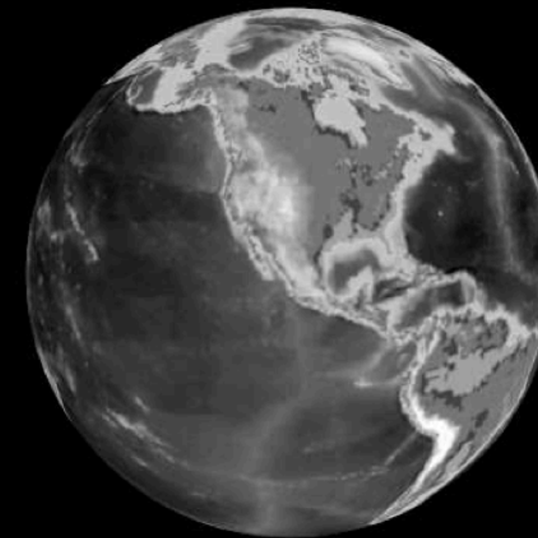
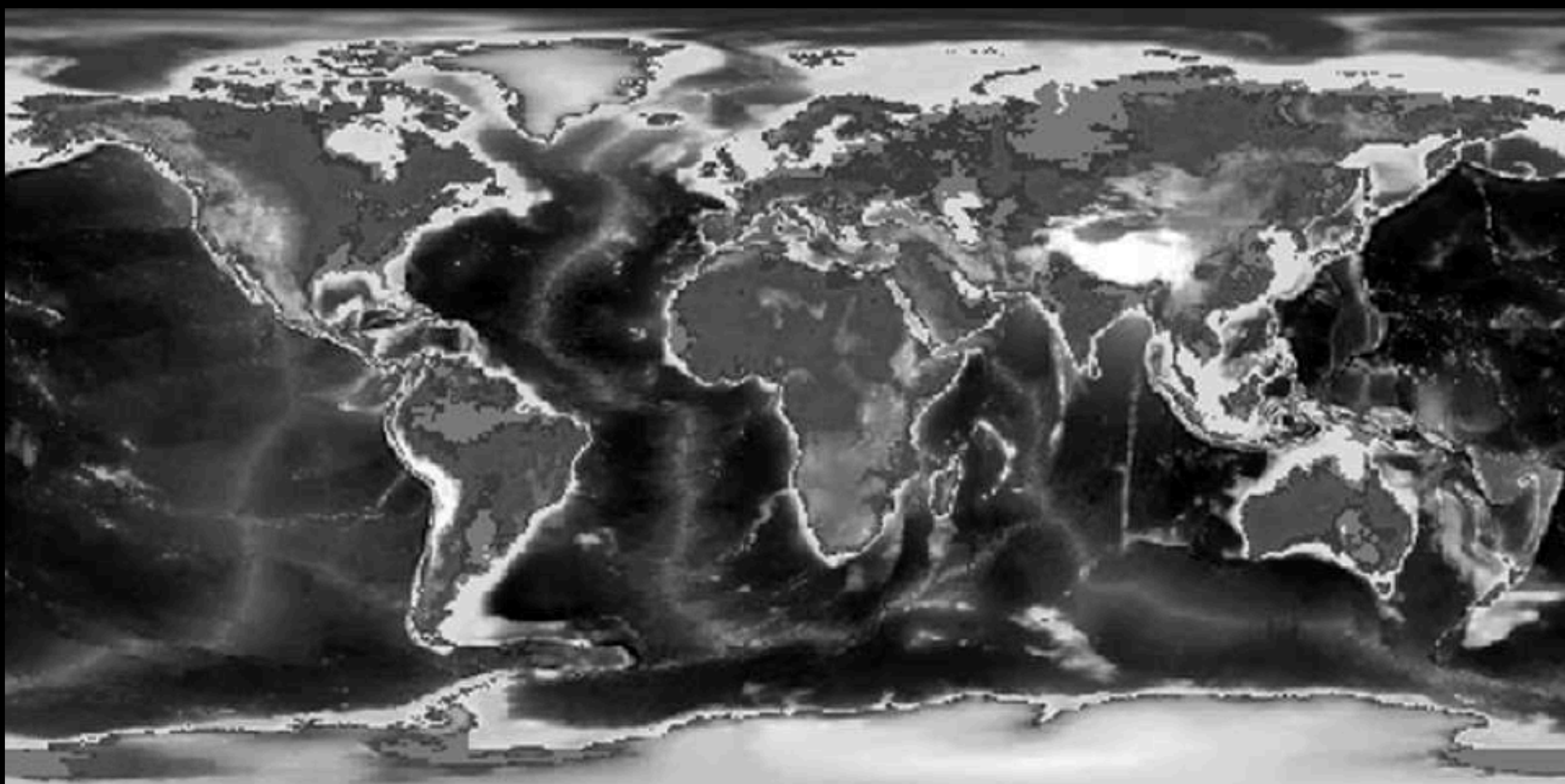


Tschmits Wikimedia Commons

- Texture is parameterized by (u,v)
- Assign polygon vertices texture coordinates
- Interpolate within polygon



Texture coordinates are per-vertex data - a position in the (u,v) space
can interpolate tex coordinates with barycentric coordinates

Texture Calibration