Shader Programming

Technical Game Development II

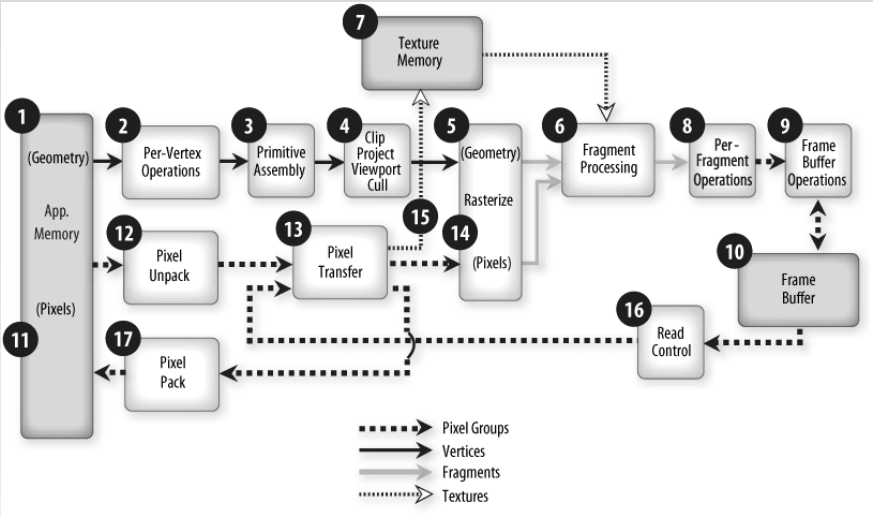
Professor Charles Rich
Computer Science Department
rich@wpi.edu

Reference: Rost, OpenGL Shading Language, 2nd Ed., AW, 2006
"The Orange Book"

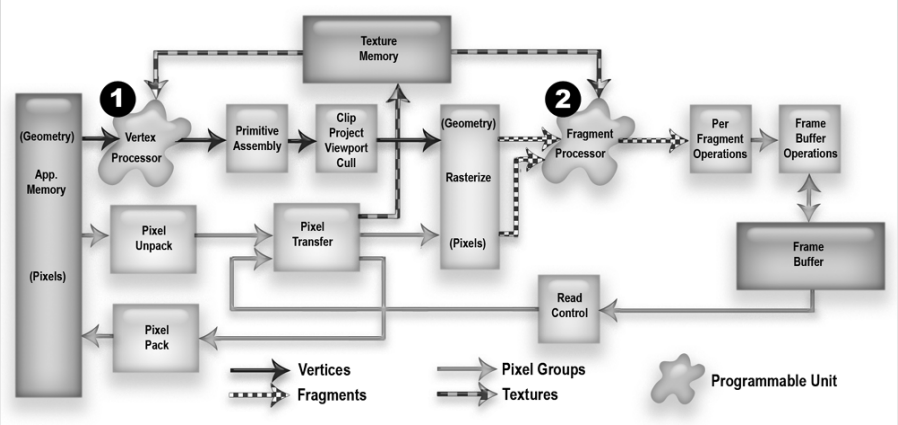
Shader Programming

- graphics hardware has replaced *fixed functionality* with *programmability* in
  - vertex processing
    - transformation
    - lighting
  - fragment (per-pixel) processing
    - reading from texture memory
    - procedurally computing colors, etc.
- OpenGL Shading Language (GLSL) is a open standard for programming such hardware
    - other languages, e.g., RenderMan

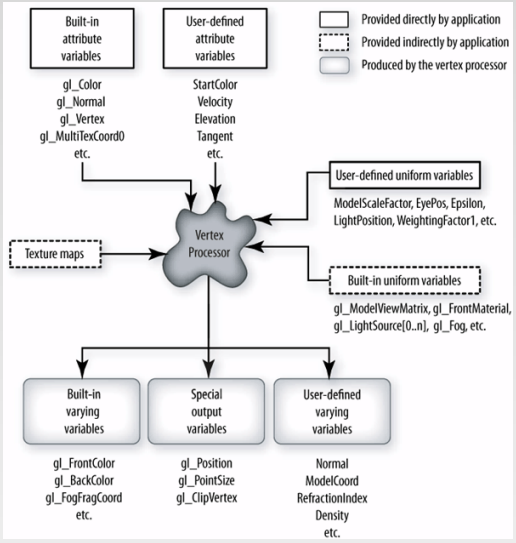
OpenGL "Fixed Functionality" Pipeline



OpenGL Programmable Processors

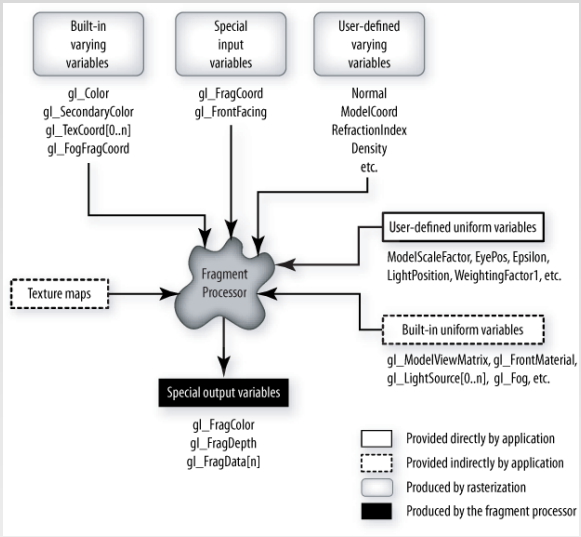


Vertex Processor



per vertex only!

Fragment (Pixel) Processor



per pixel only!

GLSL Language

- Similar to C, C++
- Builtin vector and matrix operations:
  - vec2, vec3, vec4
  - mat2, mat3, mat4
- Texture lookup
  - sampler1D, sampler2D, sampler3D

Simple Shader Program Example

- Surface temperature coloring
  - Assume temperature is known at each vertex in model
  - smoothly color surface to indicate temperature at every point (using interpolation)

Vertex Shader

```
// parameters read from application (per primitive)
uniform float CoolestTemp;
uniform float TempRange;

// incoming property of this vertex
attribute float VertexTemp;

// to communicate to the fragment shader
varying float Temperature;

void main()
{
    // communicate this vertex's temperature scaled to [0.0, 1.0]
    Temperature = (VertexTemp - CoolestTemp) / TempRange;

    // don't move this vertex
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```


Fragment Shader

```
// parameters read from application (per primitive)
uniform vec3 CoolestColor;
uniform vec3 HottestColor;

// interpolated value from vertex shader
varying float Temperature;

void main()
{
    // compute a color using built-in mix() function
    vec3 color = mix(CoolestColor, HottestColor, Temperature);

    // set this pixel's color (with alpha blend of 1.0)
    gl_FragColor = vec4(color, 1.0);
}
```

Shader Execution

- Vertex shader is run once per vertex
- Fragment shader is run once per pixel
- Many such executions can happen *in parallel*
- No communication or ordering between executions
  - no vertex-to-vertex
  - no pixel-to-pixel

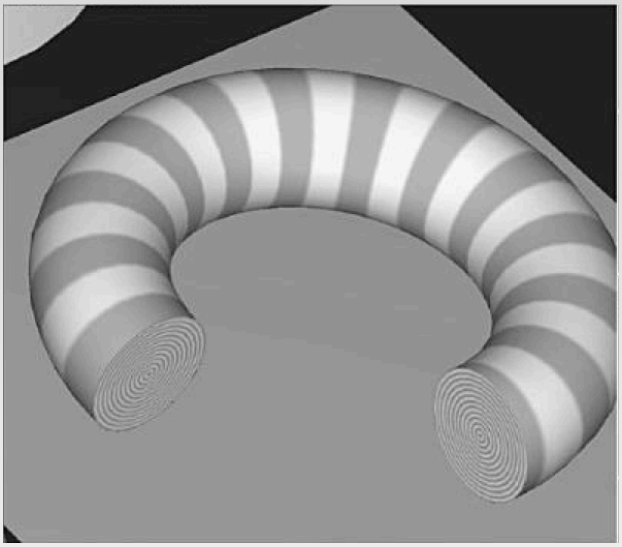
Moving Vertices in Vertex Shader

```
uniform vec3  LightPosition;
uniform vec3  SurfaceColor;
uniform vec3  Offset;
uniform float ScaleIn;
uniform float ScaleOut;
varying vec4  Color;  // color calculation for pixel shader

void main()
{
    vec3 normal = gl_Normal;
    vec3 vertex = gl_Vertex.xyz +
                  noise3(Offset + gl_Vertex.xyz * ScaleIn) * ScaleOut;

    normal = normalize(gl_NormalMatrix * normal);
    vec3 position = vec3(gl_ModelViewMatrix * vec4(vertex,1.0));
    vec3 lightVec = normalize(LightPosition - position);
    float diffuse = max(dot(lightVec, normal), 0.0);

    if (diffuse < 0.125) diffuse = 0.125;

    Color = vec4(SurfaceColor * diffuse, 1.0);
    gl_Position = gl_ModelViewProjectionMatrix * vec4(vertex,1.0);
}
```

Trivial Fragment Shader

```
varying vec4 Color;

void main()
{
    gl_FragColor = Color;
}
```


Procedural Textures - Stripes



Fragment Shader for Stripes

```
uniform vec3  StripeColor;
uniform vec3  BackColor;
uniform vec3  Width;
uniform float Fuzz;
uniform float Scale;

varying vec3 DiffuseColor;
varying vec3 SpecularColor;

void main()
{
    float scaledT = fract(gl_TexCoord[0].t * Scale);

    float frac1 = clamp(scaledT / Fuzz, 0.0, 1.0);
    float frac2 = clamp((scaledT - Width) / Fuzz, 0.0, 1.0);

    vec3 finalColor = mix(BackColor, StripeColor, frac1)
    finalColor = finalColor * DiffuseColor + SpecularColor;

    gl_FragColor = vec4(finalColor, 1.0);

}
```


Loading Shaders in jME

```
Node model = (Node) new BinaryImporter().load(
             getClass().getResource("King_Black.model"));
rootNode.attachChild(model);

GLSLShaderObjectsState shader =
    display.getRenderer().createGLSLShaderObjectsState();

shader.load(getClass().getResource("noise.vert"),
            getClass().getResource("noise.frag"));

shader.setUniform("LightPosition", 0.0f, 0.0f, 4.0f);
shader.setUniform("SurfaceColor", 1.0f, 1.0f, 1.0f);
shader.setUniform("Offset", 0.85f, 0.86f, 0.84f);
shader.setUniform("ScaleIn", 1.0f);
shader.setUniform("ScaleOut", 1.0f);
shader.setEnabled(true);

rootNode.setRenderState(shader);
```

Shaders in Other Engines

- C4
  - material type selection (predefined shaders)
  - shader editor (restricted functionality)
  - no direct access to shader code
- Unity
  - predefined shaders
  - can write your own in GLSL

Lots More You Can Do With Shaders

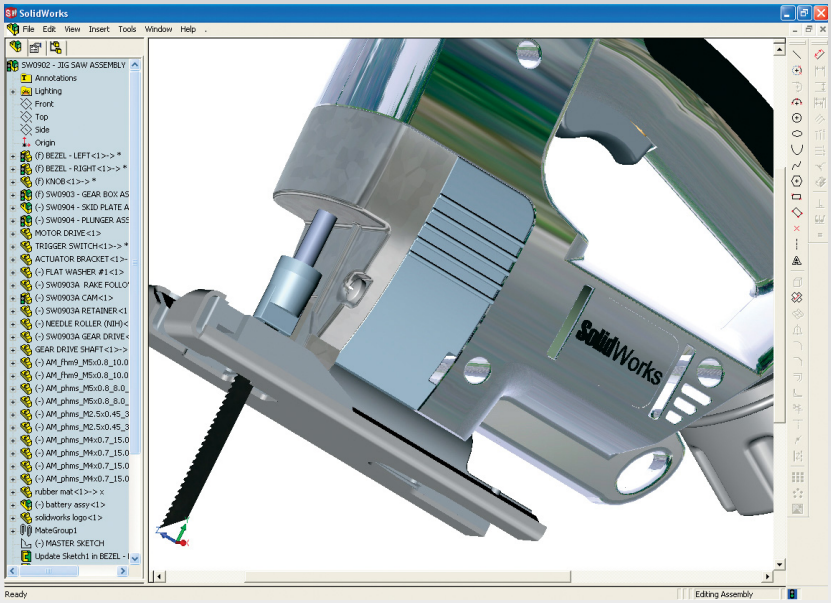
- Procedural Textures
  - patterns (stripes, etc.)
  - bump mapping
- Lighting Effects
- Shadows
- Surface Effects
  - refraction, diffraction
- Animation
  - morphing
  - particles

Lots More ...

- Anti-aliasing
- Non-photorealistic effects
  - hatching, meshes
  - technical illustration
- Imaging
  - sharpen, smooth, etc.
- Environmental effects (RealWorldz)
  - terrain
  - sky
  - ocean

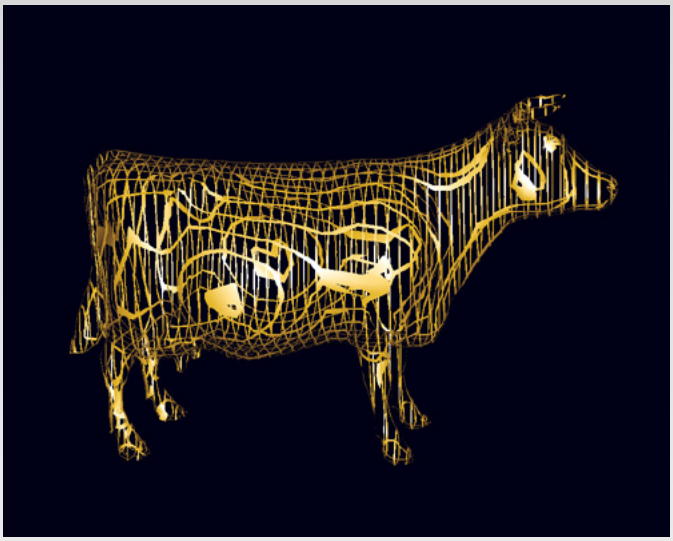
Shader Programming

- Seems to lie on the boundary between art and tech
  - programming is hard-core (parallel algorithms)
  - but intended result is often mostly aesthetic

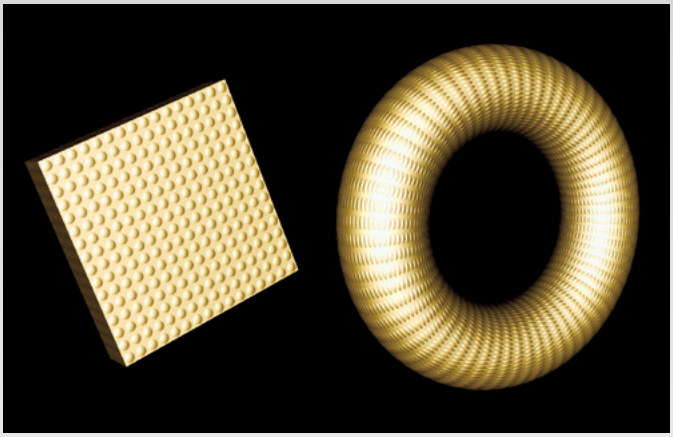


Screen shot of the SolidWorks application, showing a jigsaw rendered with OpenGL shaders to simulate a chrome body, galvanized steel housing, and cast iron blade. (Courtesy of SolidWorks Corporation)

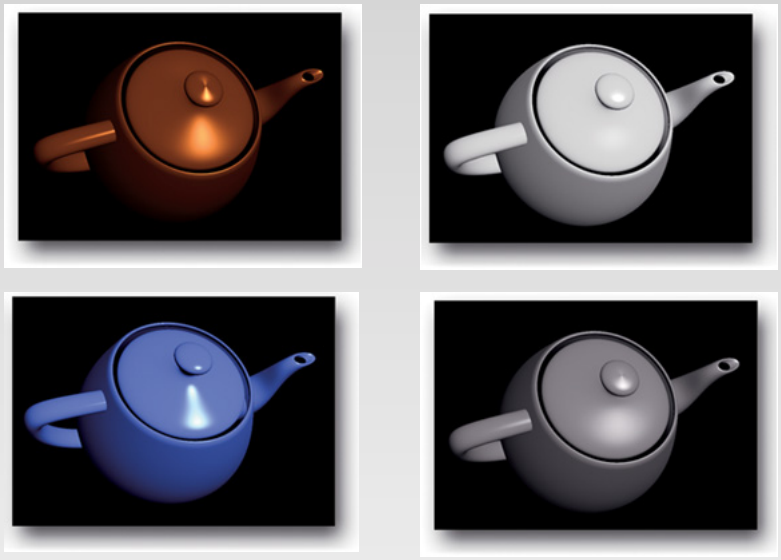
Different glyphs applied to a cube using the glyph bombing shader described in Section 10.6. (3Dlabs, Inc.)



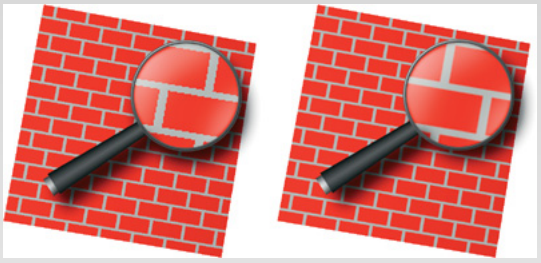
The lattice shader presented in Section 11.3 is applied to the cow model. (3Dlabs, Inc.)



A simple box and a torus that have been bump-mapped using the procedural method described in Section 11.4. (3Dlabs, Inc.)



A variety of materials rendered with Ward's BRDF model (see Section 14.3) and his measured/fitted material parameters.



Brick shader with and without antialiasing. On the left, the results of the brick shader presented in Chapter 6. On the right, results of antialiasing by analytic integration using the brick shader described in Section 17.4.5. (3Dlabs, Inc.)

A variety of screen shots from the 3Dlabs RealWorldz demo. Everything in this demo is generated procedurally using shaders written in the OpenGL Shading Language. This includes the planets themselves, the terrain, atmosphere, clouds, plants, oceans, and rock formations. Planets are modeled as mathematical spheres, not height fields. These scenes are all rendered at interactive rates on current generation graphics hardware