Use Cg Language

Adapted from
Suresh Venkatasubramanian
Klaus Mueller

What is Cg?

- Cg stands for “C for Graphics”.
- Developed by Nvidia

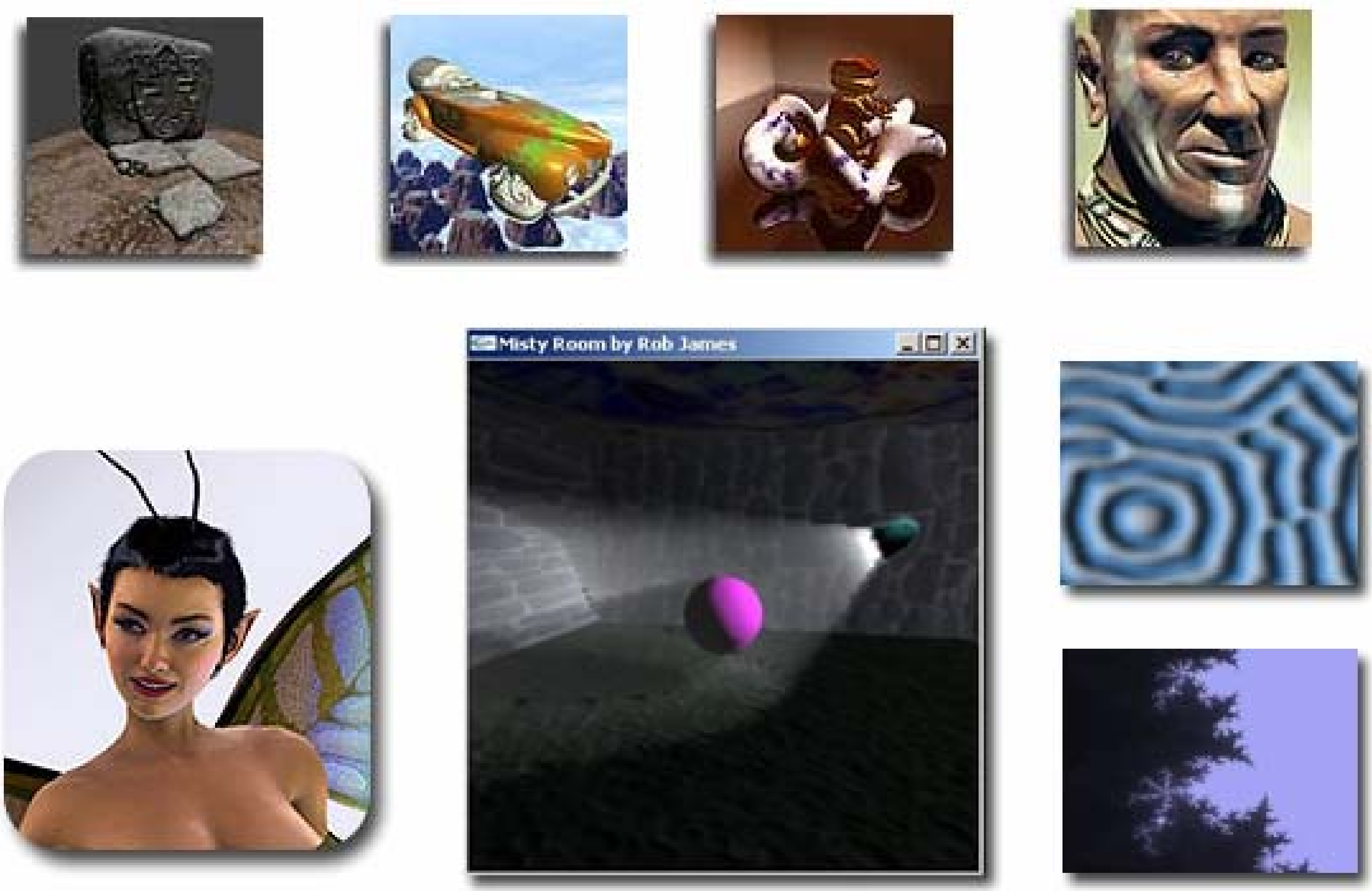
- Cg compiles to code that can be executed by a GPU’s programmable fragment or vertex processor

- Cg is “theoretically” cross-platform working for OpenGL and DirectX

What is Cg?

- Can work with OpenGL as well as Direct3D
- CG compiler produces OpenGL or Direct3D code
- OpenGL or Direct3D drivers perform final translation into hardware-executable code
  - core CG runtime library (CG prefix)
  - cgGL and cgD3D libraries

What is Cg used for?



What does Cg look like?

Assembly

```
…
RSQR  R0.x, R0.x;
MULR  R0.xyz, R0.xxxx, R4.xyzz;
MOVR  R5.xyz, -R0.xyzz;
MOVR  R3.xyz, -R3.xyzz;
DP3R  R3.x, R0.xyzz, R3.xyzz;
SLTR  R4.x, R3.x, {0.000000}.x;
ADDR  R3.x, {1.000000}.x, -R4.x;
MULR  R3.xyz, R3.xxxx, R5.xyzz;
MULR  R0.xyz, R0.xyzz, R4.xxxx;
ADDR  R0.xyz, R0.xyzz, R3.xyzz;
DP3R  R1.x, R0.xyzz, R1.xyzz;
MAXR  R1.x, {0.000000}.x, R1.x;
LG2R  R1.x, R1.x;
MULR  R1.x, {10.000000}.x, R1.x;
EX2R  R1.x, R1.x;
MOVR  R1.xyz, R1.xxxx;
MULR  R1.xyz, {0.900000, 0.800000,
     1.000000}.xyzz, R1.xyzz;
DP3R  R0.x, R0.xyzz, R2.xyzz;
MAXR  R0.x, {0.000000}.x, R0.x;
MOVR  R0.xyz, R0.xxxx;
ADDR  R0.xyz, {0.100000, 0.100000,
     0.100000}.xyzz, R0.xyzz;
MULR  R0.xyz, {1.000000, 0.800000,
     0.800000}.xyzz, R0.xyzz;
ADDR  R1.xyz, R0.xyzz, R1.xyzz;
```

Cg

```
…
float3 cSpec = pow(max(0, dot(Nf, H)), phongExp).xxx;
float3 cPlastic = Cd * (cAmbi + cDiff) + Cs * cSpec;
…
```

Shading Language (RenderMan™)

```
…
color cSpec = phong(Nf,V,phongExp);
Ci = Oi * (FinalColor = DiffuseColor *
     (AmbientLight + DiffuseLight)) + SpecularColor
     * cSpec;
…
```

Where do I get Cg?

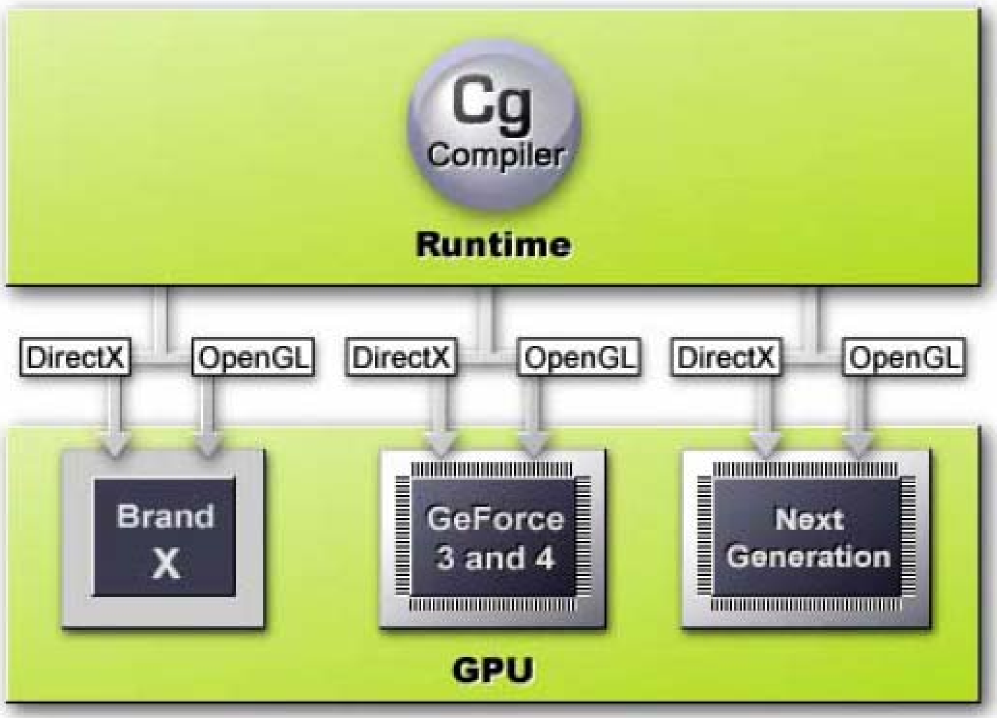
- http://developer.nvidia.com/page/cg_main.html
- Download the latest Cg Toolkit:
  - Cg Compiler
  - Cg Runtime
  - Cg User's Manual
  - Cg Browser
  - Sample Cg Shaders
- The installer setup the appropriate environment variables (PATH, CG_LIB_PATH, CG_INC_PATH).

Compilation

- To interface Cg programs with application:
  - compile the program with appropriate profile
    - dependent on underlying hardware for shader versions
  - range of profiles will grow with GPU advances
    - OpenGL: vp20, vp30, fp30, fp40 ...
- Link the program to the application program
- Can perform compilation at
  - compile time (static)
  - runtime (dynamic)

How can I use Cg?

- Your application must call the Cg Runtime to invoke the Cg programs and pass the appropriate parameters.



Cg Runtime

- The Cg Runtime can be more challenging than Cg itself.

- For complete documentation on the Cg Runtime, see the Cg User's Manual.

Cg Runtime

- Can take advantage of
  - latest profiles
  - optimization of existing profiles
- No dependency issues
  - register names, register allocations
- In the following, use OpenGL to illustrate
  - Direct3D similar methods

Preparing a Cg Program

- First, create a context:
  - context = cgCreateContext()
- Compile a program by adding it to the context:
  - program = cgCreateProgram(context, programString, profile, name, args)
- Loading a program (pass to the 3D API):
  - cgGLLoadProgram(program)

Running a Cg Program

- Executing the profile:
  - cgEnableProfile(CG_PROFILE_ARBVP1)
- Bind the program:
  - cgGLBindProgram(program)
- After binding, the program will execute in subsequent drawing calls
  - for every vertex (for vertex programs)
  - for every fragment (for fragment programs)
  - these programs are often called *shaders*

Cg Runtime Example

```
void CgGLInit()
{
  // Create the fragment program
  fragmentProgram = cgCreateProgramFromFile(
                    context, CG_SOURCE, "FragmentProgram.cg",
                    fragmentProfile, "FragmentProgram", 0);

  // Load the program
  cgGLLoadProgram(fragmentProgram);

  // Grab some parameters.
  someColor = cgGetNamedParameter(fragmentProgram,
                                  "SomeColor");
 cgGLSetParameter4fv(someColor, constantColor);
}
// Called to render the scene
void Display()
{
 // Bind the programs
 cgGLBindProgram(fragmentProgram);
  // Draw scene
  // ...
}
```

Running a Cg Program

- One one vertex / fragment program can be bound at a time
  - the same program will execute unless another program is bound
- Disable a profile by:
  - cgGLDisableProfile()
- Release resources:
  - cgDestroyProgram(program)
  - cgDestroyContext(context)
  - the latter destroys all programs as well

Error Handling

- There are core CG routines that retrieve global error variables:
  - error = cgGetError()
  - cgGetErrorString(error)
  - cgSetErrorCallback(MyErrorCallback)

Anatomy of a Cg Vertex Program

Entry Point to Cg Program. Followed by a parameter list.

```
void main(float4 Pobject       : POSITION,
        uniform float4x4 ModelViewProj,

        out float4 HPosition     : POSITION,
        out float4 oColor        : COLOR0)
{
   // compute homogeneous position of vertex for rasterizer
   HPosition = mul(ModelViewProj, Pobject);

   oColor = float4(0,1,0,1);
}
```

- <= Varying Input Parameter (per-vertex value)
- <= Uniform Input Parameter (constant value)
- <= Output Parameter (passed to fragment proc)
- <= Output Parameter (passed to fragment proc)
- <= Matrix by Vector multiplication. Output Position transformed and set.
- <= Output Color Set to GREEN.

Body of the Cg Program, uses input params to compute out params.

Anatomy of a Cg Fragment Program

Entry Point to Cg Program. Followed by a parameter list.

```
void main( float4 iColor        : COLOR0,
        float3 iNormal        : TEXCOORD0,

        out float4 oColor : COLOR)
{

    oColor =  float4(normalize(iNormal),1) * iColor;
}
```

<= Varying Input Parameters (interpolated from the output of the vertex program)

<= Output Parameter passed to GPU Raster Operations

<= The output color is set to the product of the normalized texcoord0 and color0 input.

Body of the Cg Program, uses input params to compute out params.

Simple Vertex Program

```
struct C3E1v_Output {
  float4 position : POSITION;
  float4 color    : COLOR;
};

C3E1v_Output C3E1v_anyColor(float2 position : POSITION,
                            uniform float4 constantColor)
{
  C3E1v_Output OUT;

  OUT.position = float4(position, 0, 1);
  OUT.color = constantColor;  // Some RGBA color

  return OUT;
}
```

semantics

to rasterizer

- *Semantics* connect Cg program with graphics pipeline
  - here: POSITION and COLOR

Uniform vs. Varying Parameters

```
struct C3E1v_Output {
  float4 position : POSITION;
  float4 color    : COLOR;
};

C3E1v_Output C3E1v_anyColor(float2 position : POSITION,
                            uniform float4 constantColor)
{
  C3E1v_Output OUT;

  OUT.position = float4(position, 0, 1);
  OUT.color = constantColor;  // Some RGBA color

  return OUT;
}
```

varying

uniform

- Varying: values vary per vertex or fragment
  - interfaced via semantics
- Uniform: remain constant
  - interfaced via handles

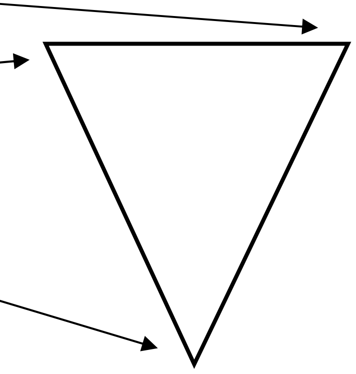
Passing Parameters

- Assume these shader variables:
  - float4 position : POSITION
  - float4 color : COLOR0
- Get the handle for color by:
  - color = cgGetNamedParameter(program, "IN.color")
- Can set the value for color by:
  - cgGLSetParameter4f(color, 0.5f, 1.0f, 0.5f, 1.0f)
- Uniform variables are set infrequently:
  - example: modelViewMatrix

Passing Parameters

- Set other variables via OpenGL semantics:
  - glVertex, glColor, glTexCoord, glNormal,…
- Example: rendering a triangle with OpenGL:

```
glBegin(GL_TRIANGLES);
    glVertex( 0.8,  0.8);
    glVertex(-0.8,  0.8);
    glVertex( 0.0, -0.8);
glEnd();
```



- glVertex affects POSITION semantics and updates/sets parameter in vertex shader

Example 1

- Vertex program

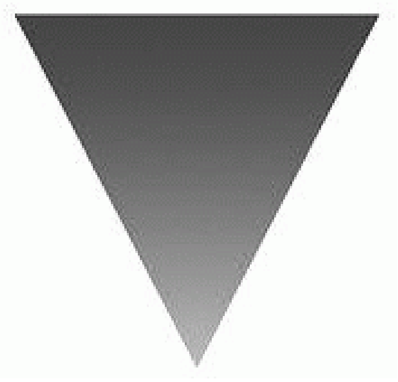
```
struct C3E2v_Output {
  float4 position : POSITION;
  float4 color    : COLOR;
  float2 texCoord : TEXCOORD0;
};

C3E2v_Output C3E2v_varying(float2 position : POSITION,
                           float4 color    : COLOR,
                           float2 texCoord : TEXCOORD0)
{
  C3E2v_Output OUT;

  OUT.position = float4(position, 0, 1);
  OUT.color    = color;
  OUT.texCoord = texCoord;

  return OUT;
}
```

  - OUT parameter values are passed to fragment shader

Example 1

- Result, assuming:
  - a fragment shader that just passes values through
  - OpenGl program

```
glBegin(GL_TRIANGLES);
   glVertex( 0.8,  0.8); glColor(dark);
   glVertex(-0.8,  0.8); glColor(dark);
   glVertex( 0.0, -0.8); glColor(light);
glEnd();
```



Example 2

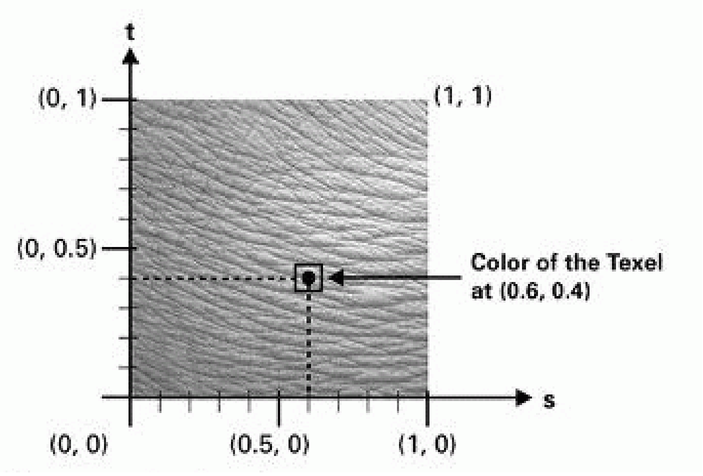
- Fragment program, following example 1 vertex program

```
struct C3E3f_Output {
  float4 color : COLOR;
};

C3E3f_Output C3E3f_texture(float2 texCoord : TEXCOORD0,
                           uniform sampler2D decal)
{
  C3E3f_Output OUT;
  OUT.color = tex2D(decal, texCoord);
  return OUT;
}
```

- Sampler2D is a texture object
  - other types exist: samplerRect, samplerCUBE, etc

Example 2

- Tex2D(decal, texCoord) performs a texture-lookup
  - sampling, filtering, and interpolation depends on texture type and texture parameters
  - advanced fragment profiles allow sampling using texture coordinate sets from other texture units (*dependent textures*)



Example 2

- Result

Math Support

- A rich set of math operators and library functions
  - +-/*, sin, cos, floor, etc....
  - no bit-wise operators yet
- Full floating point operations
- Function overloading
  - for example, abs() function accepts float4, float2

Syntax

- IN keyword
  - call by value
  - parameter passing by value
- OUT keyword
  - indicates when the program returns

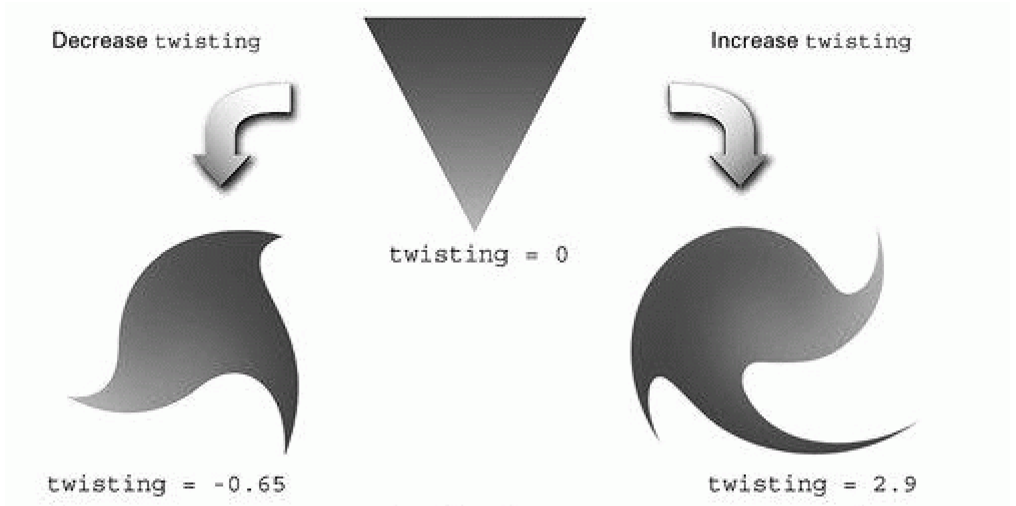
Example 3

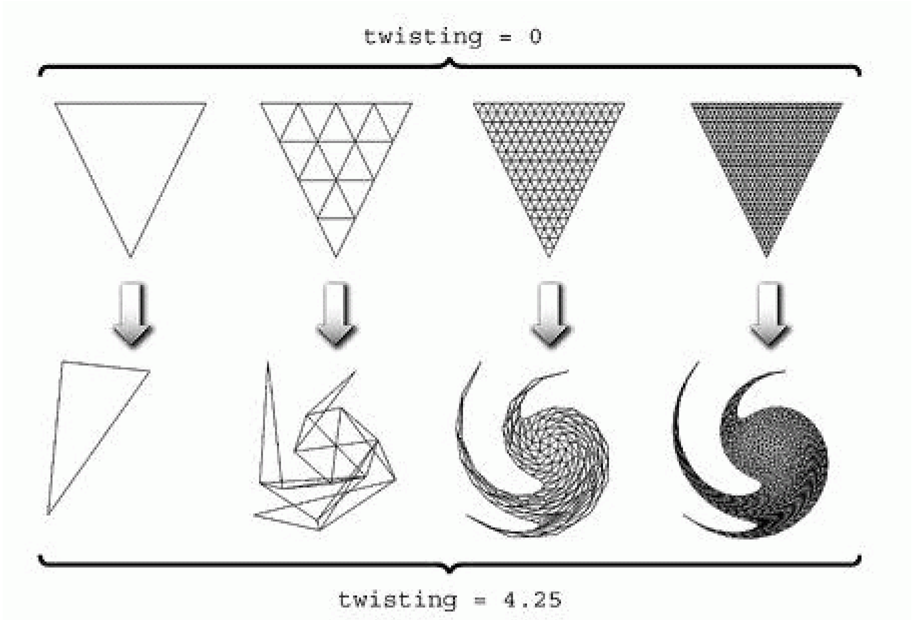
- 2D Twisting

```
struct C3E4_Output {
  float4 position : POSITION;
  float4 color    : COLOR;
};

C3E4_Output C3E4v_twist(float2 position : POSITION,
                        float4 color    : COLOR,

                        uniform float twisting)
{
  C3E4_Output OUT;
  float angle = twisting * length(position);
  float cosLength, sinLength;
  sincos(angle, sinLength, cosLength);
  OUT.position[0] = cosLength * position[0] +
                   -sinLength * position[1];
  OUT.position[1] = sinLength * position[0] +
                    cosLength * position[1];
  OUT.position[2] = 0;
  OUT.position[3] = 1;
  OUT.color = color;
  return OUT;
}
```

Example 3

- Result





finer meshes give better results

Example 4

- Double Vision: vertex program

```
void C3E5v_twoTextures(float2 position : POSITION,
                       float2 texCoord : TEXCOORD0,

                   out float4 oPosition  : POSITION,
                   out float2 leftTexCoord : TEXCOORD0,
                   out float2 rightTexCoord : TEXCOORD1,

               uniform float2 leftSeparation,
               uniform float2 rightSeparation)
{


  oPosition     = float4(position, 0, 1);
  leftTexCoord  = texCoord + leftSeparation;
  rightTexCoord = texCoord + rightSeparation;


}
```

- OUT is defined via semantics in the prototype

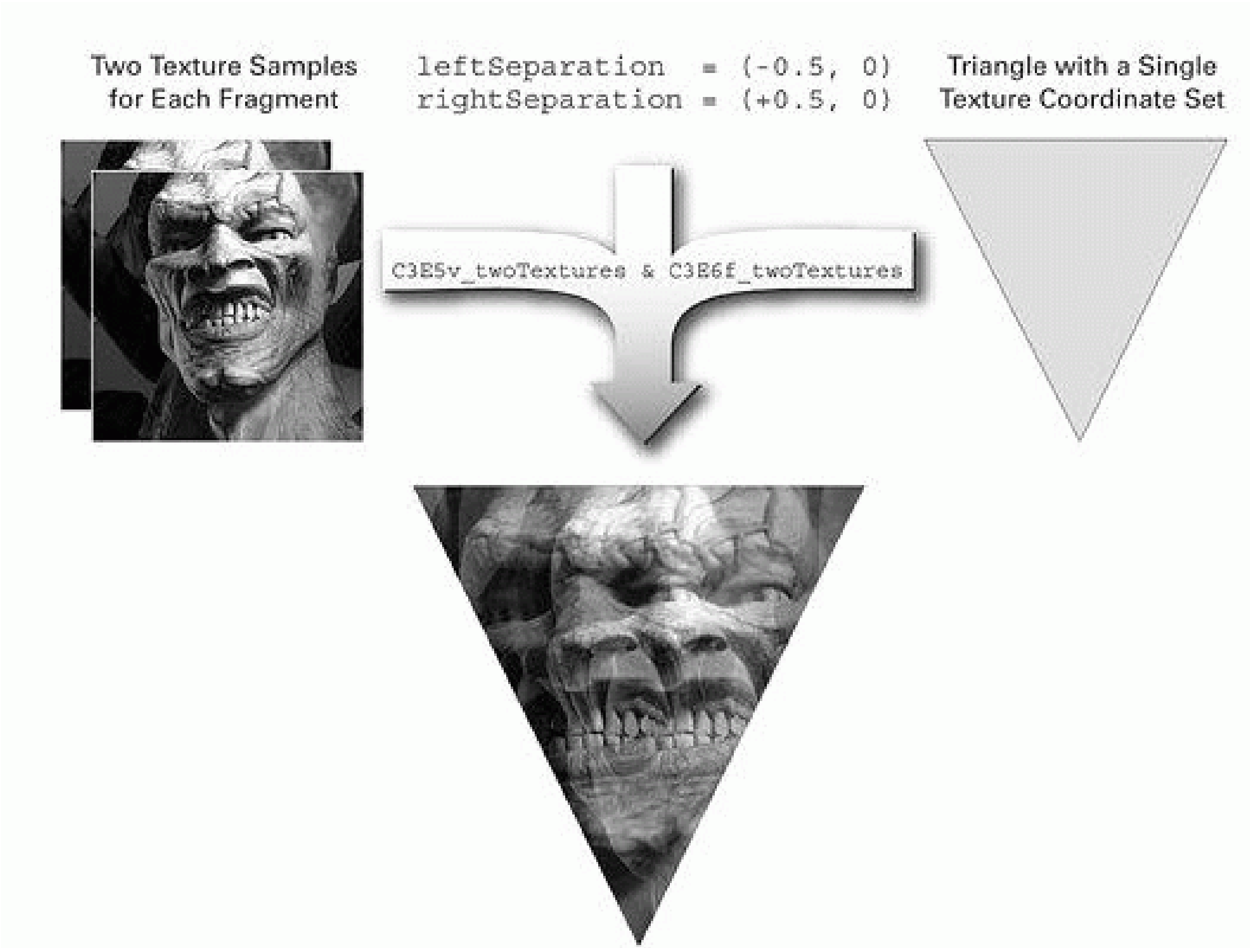
Example 4

- Double Vision: fragment program #1
  - samples the same texture (named *decal*) twice
- lerp(a, b, weight): linear interpolation
  - result = (1-weight) $\times$ a + weight $\times$ b

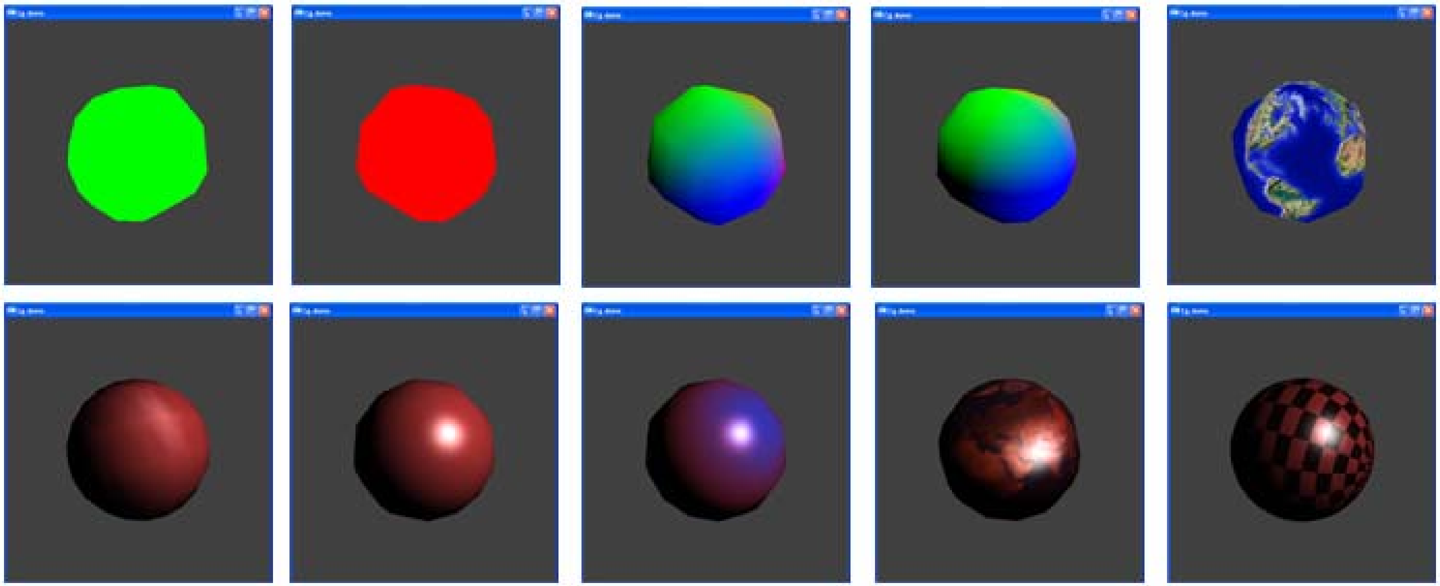
```
void C3E6f_twoTextures(float2 leftTexCoord  : TEXCOORD0,
                       float2 rightTexCoord : TEXCOORD1,

                   out float4 color : COLOR,

               uniform sampler2D decal)
{
  float4 leftColor  = tex2D(decal, leftTexCoord);
  float4 rightColor = tex2D(decal, rightTexCoord);
  color = lerp(leftColor, rightColor, 0.5);
}
```

Example 4

- Result

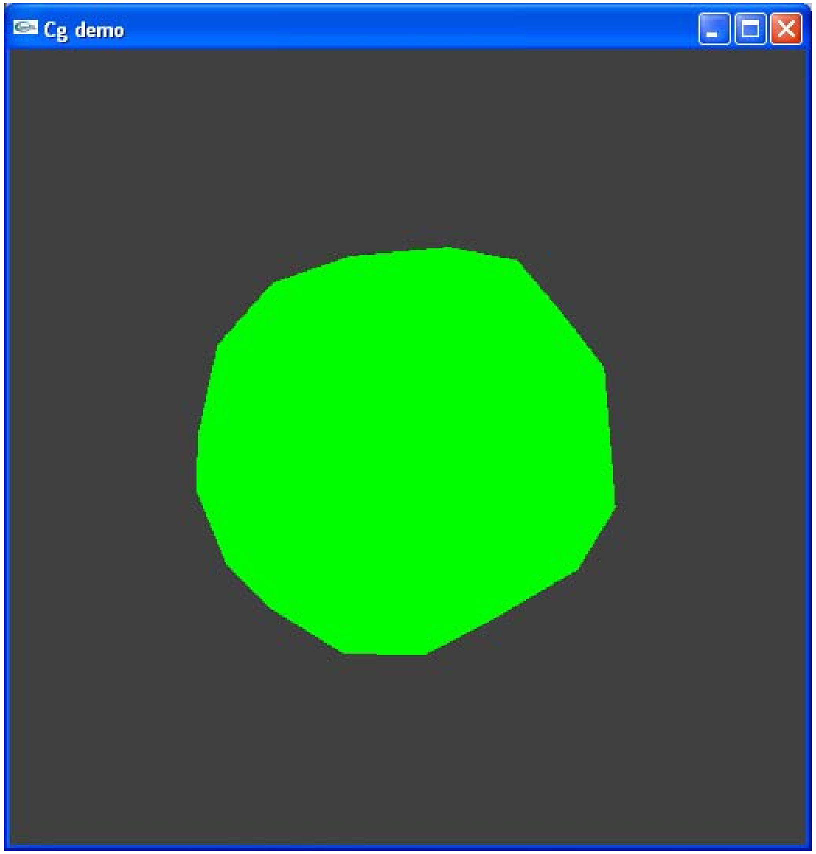


More Cg Examples



Green Sphere

- Uses a simple vertex program to color a sphere solid green.
- The fragment program just sets its color output to its color input (does nothing but pass the data along).

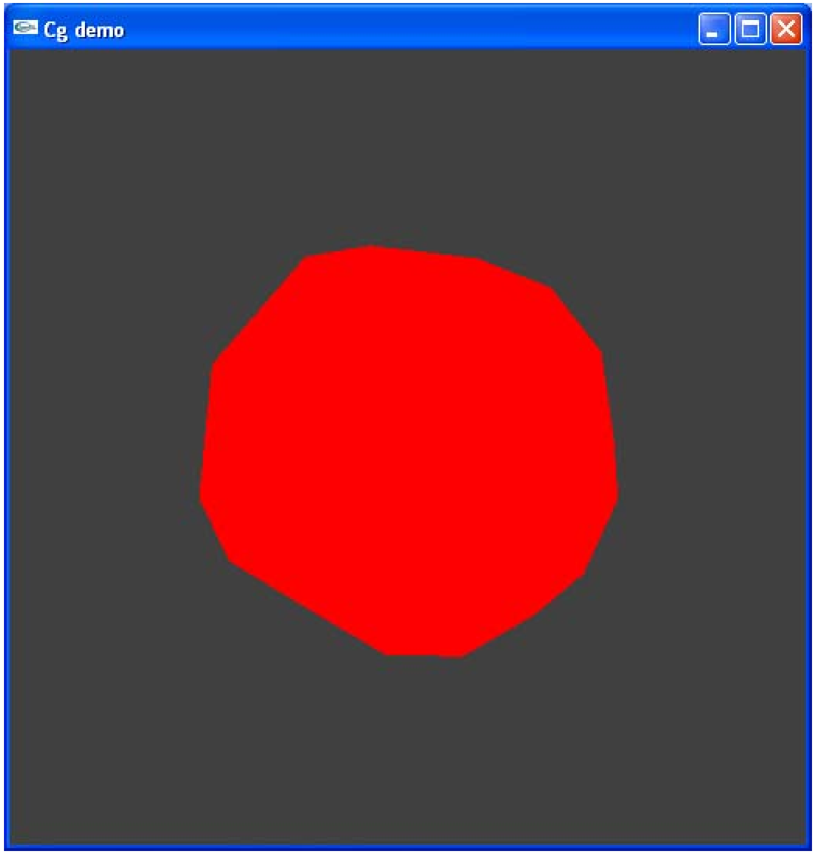


Color Sphere

- Same as green sphere, but the Cg Runtime is used to pass color in as a uniform parameter.

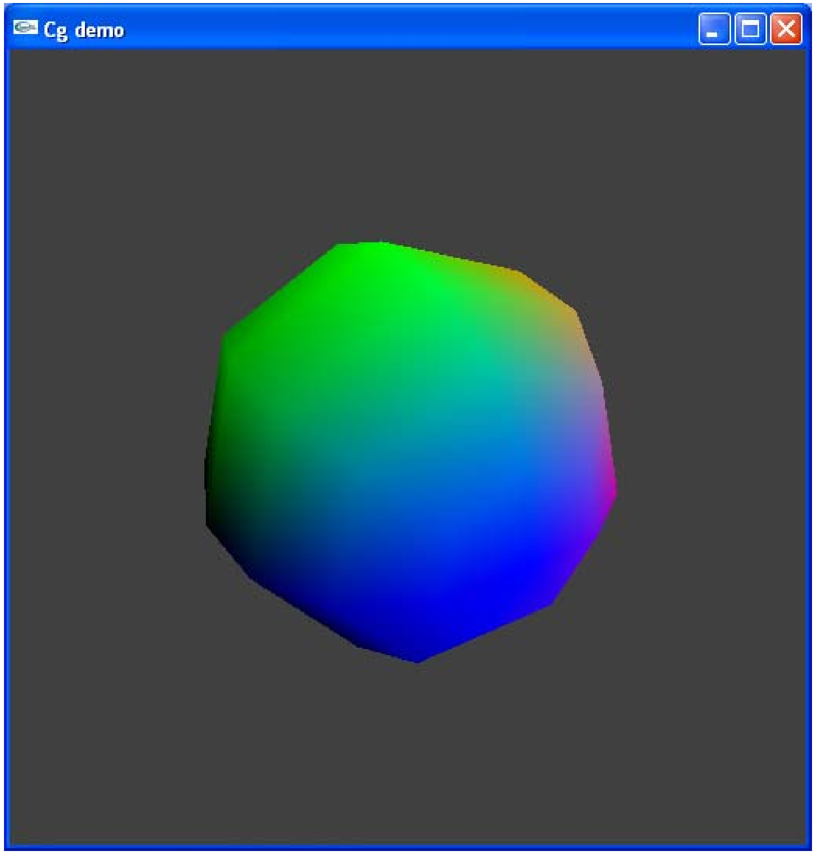
- float myColor[4] = { 1, 0, 0,1 };

  cgGLSetParameter4fv(cgGetNamedParameter(vertexProgram, "iColor"),myColor);



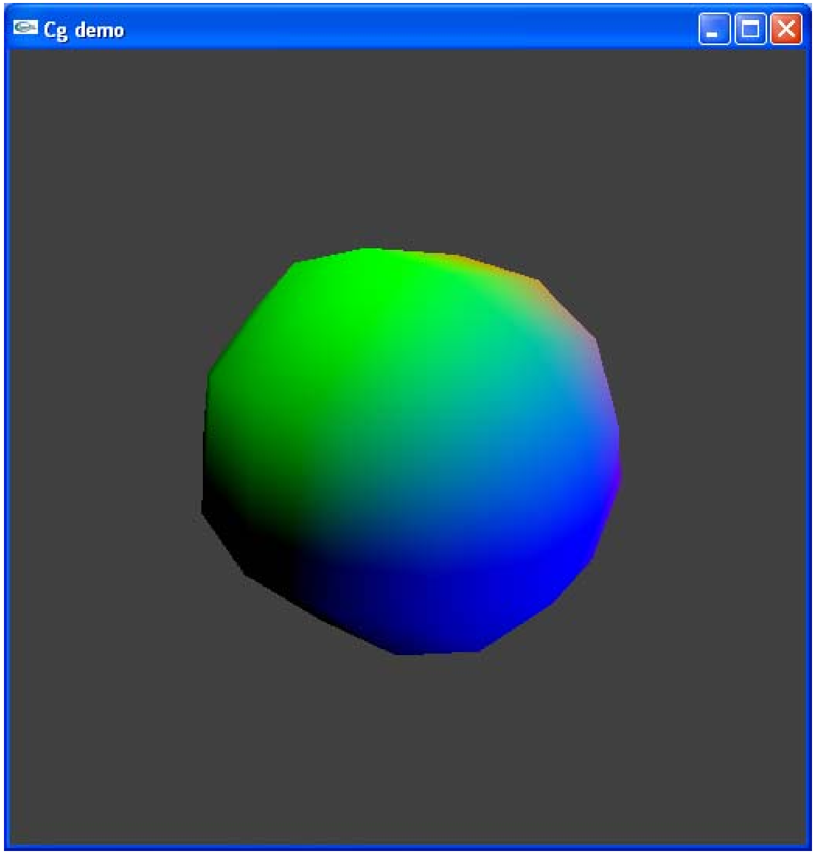
Normal Vertex Sphere

- Uses a vertex program to shade a sphere with rgb components equal to the normal components.
- The normals are passed via a varying vertex parameter.



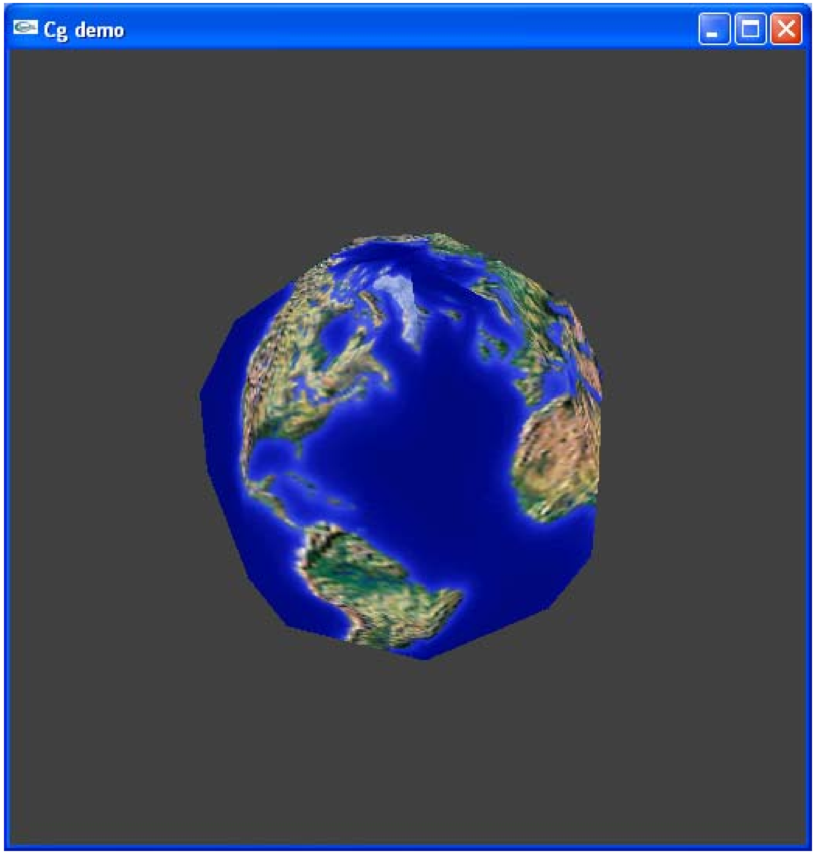
Normal Fragment Sphere

- Uses a fragment program to set the sphere color to the normalized interpolated vertex normal ?!
- The normals are passed to the vertex program via a varying parameters, and are passed to the fragment program via texture coordinates.



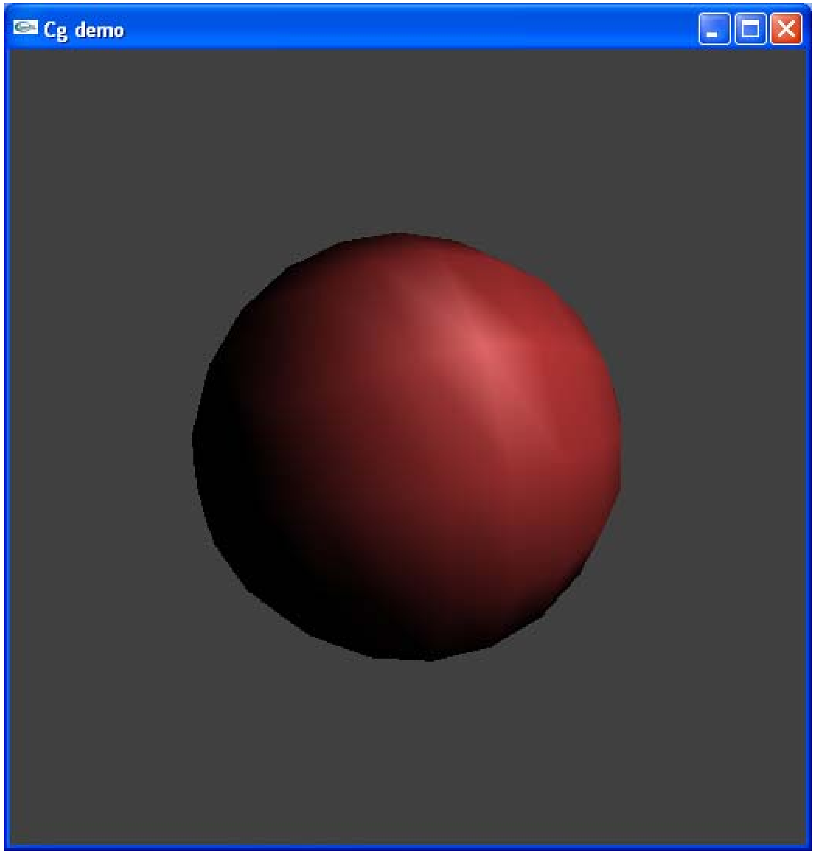
Texture Fragment Sphere

- Uses a fragment program to map a texture of the world to a sphere.
- The texture coordinates are passed to the vertex program via a varying parameter.
- The texture is passed directly to the fragment program as a "sampler".



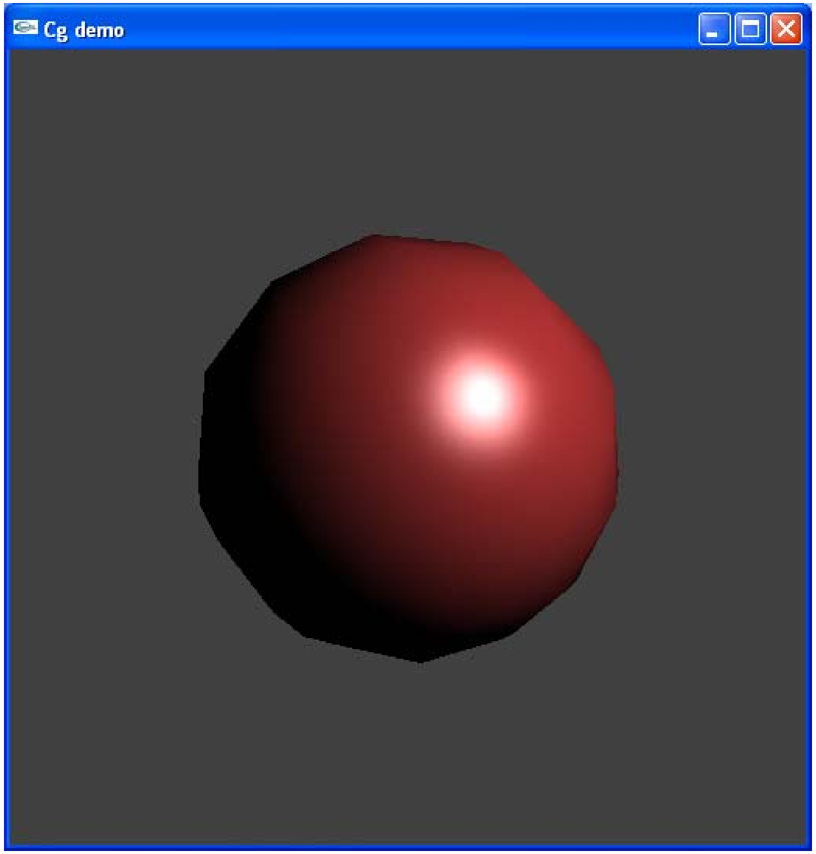
“Plastic” Per-Vertex Shading

- Uses a vertex program to calculate standard "fixed function" lighting (aka plastic).
- Note the “faceted” nature of the shading, this will be addressed in the next example.



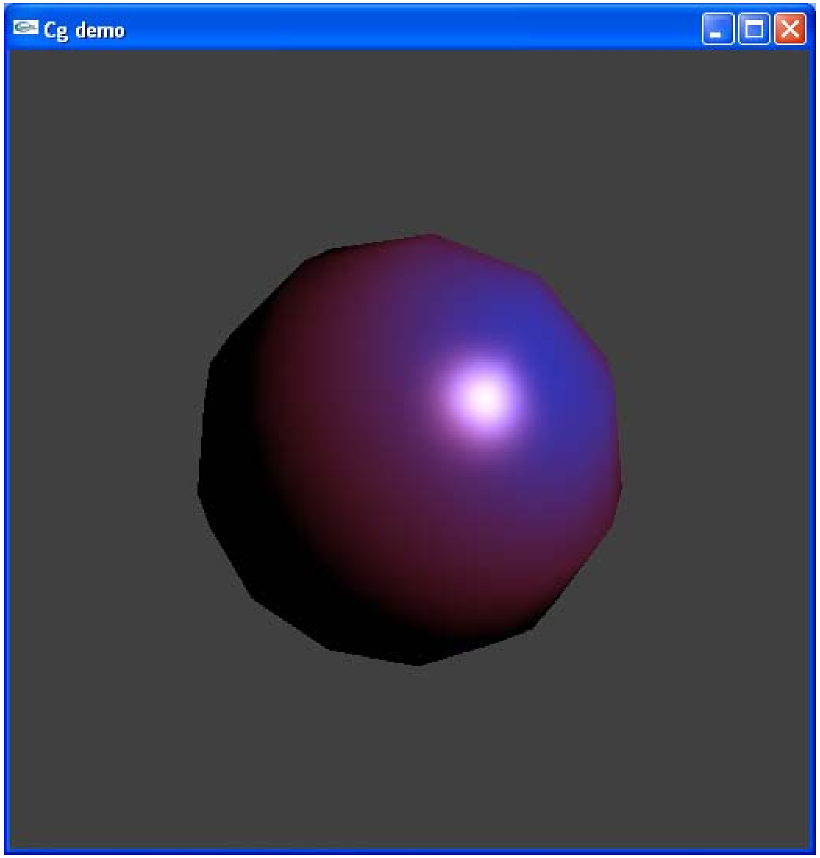
“Plastic” Per-Fragment Shading

- Uses a fragment program to perform standard "fixed-function" lighting (aka plastic).
- Note that the per-fragment calculations perform a much more accurate rendering (But slower)



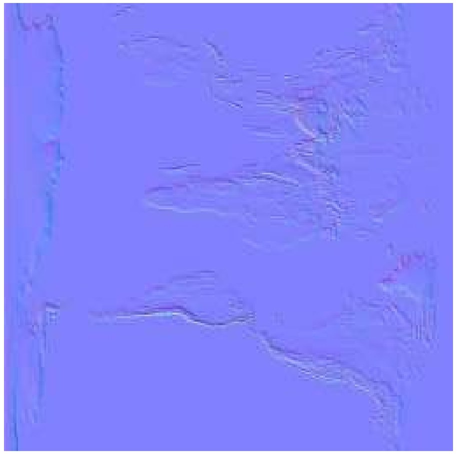
Color Shaping using "lerp"

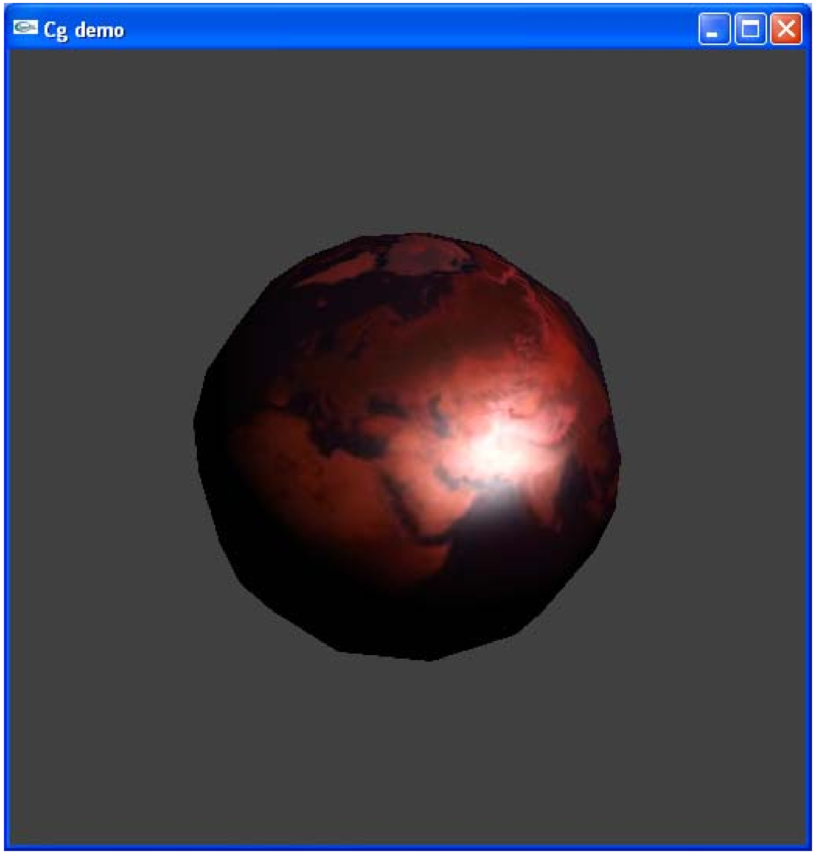
- Uses a fragment program to perform color shaping on the diffuse and specular components of the standard "fixed function" lighting.
- Color shaping is achieved by lerp'ing between two colors based on the diffuse and specular float values.
- float3 specular = lerp(Ks0,Ks1,specularLight) * lightColor * specularLight;



Normal Mapping

- Uses a fragment program to read normal and color information from texture maps and perform standard "fixed function" plastic lighting.





Homework2

- Please download cg toolkit
- Run the examples on your machine, make them working
- Study the examples for basic cg programming, together with our textbook