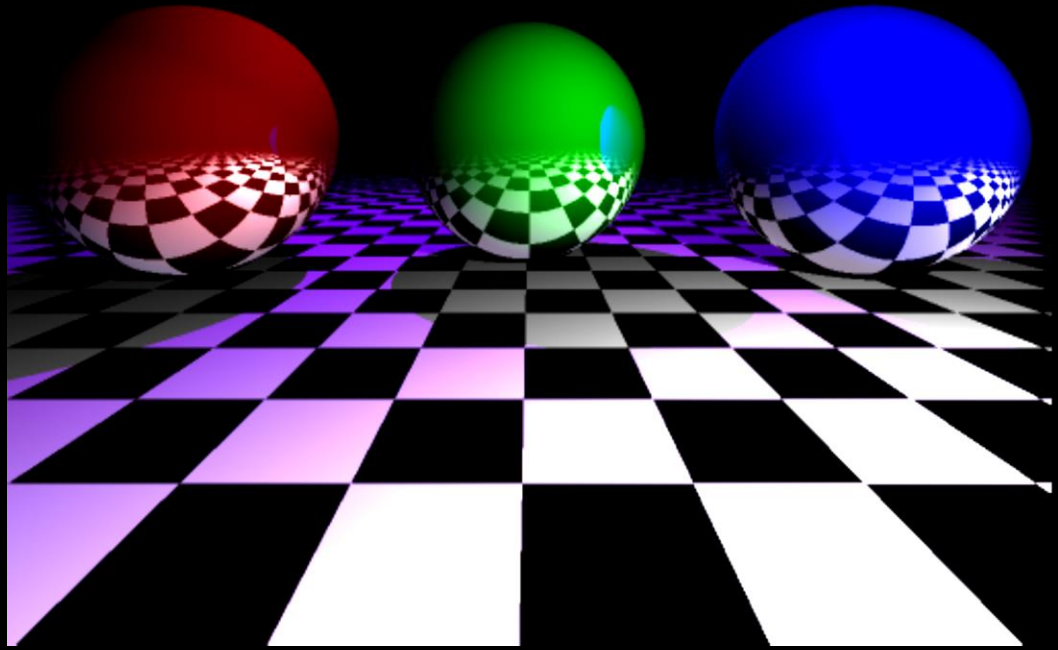
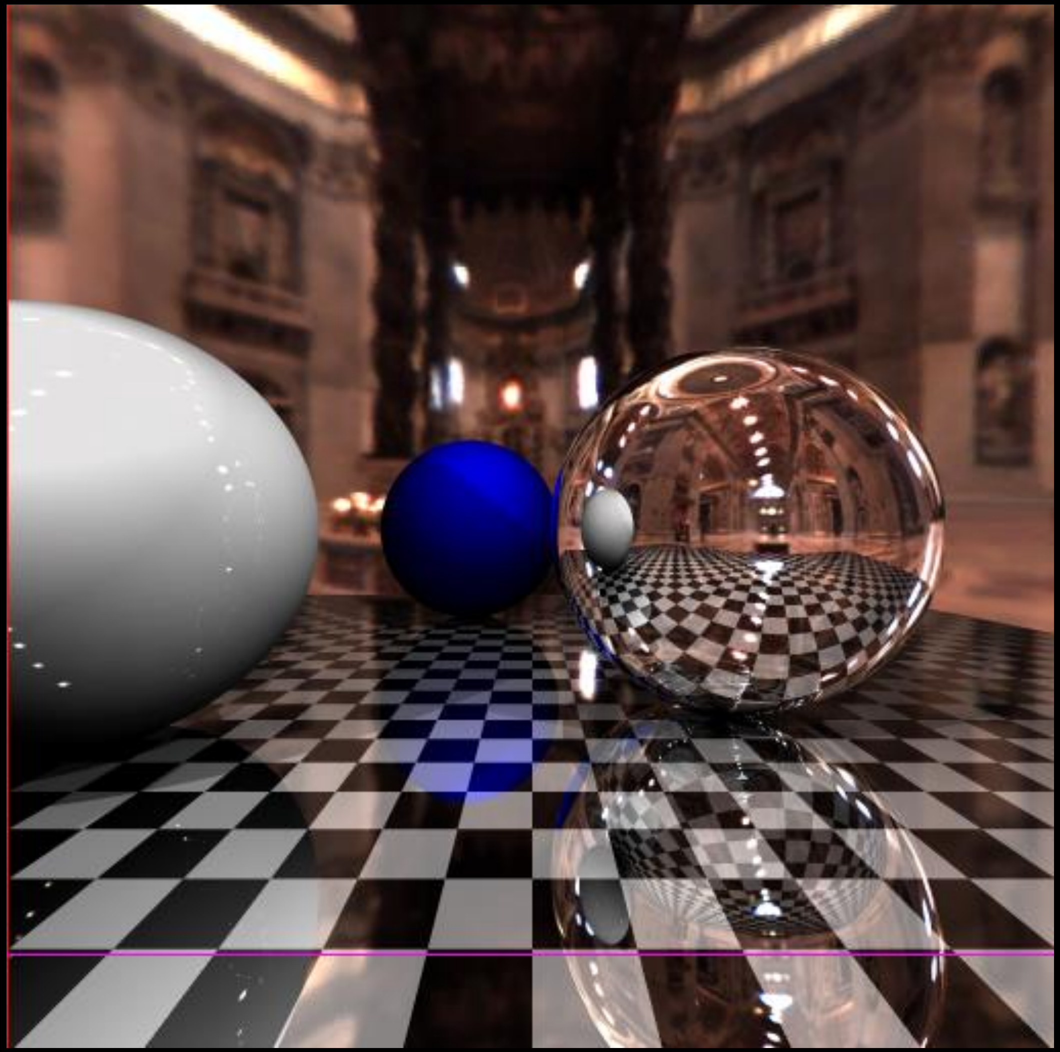
INFOGR – Computer Graphics

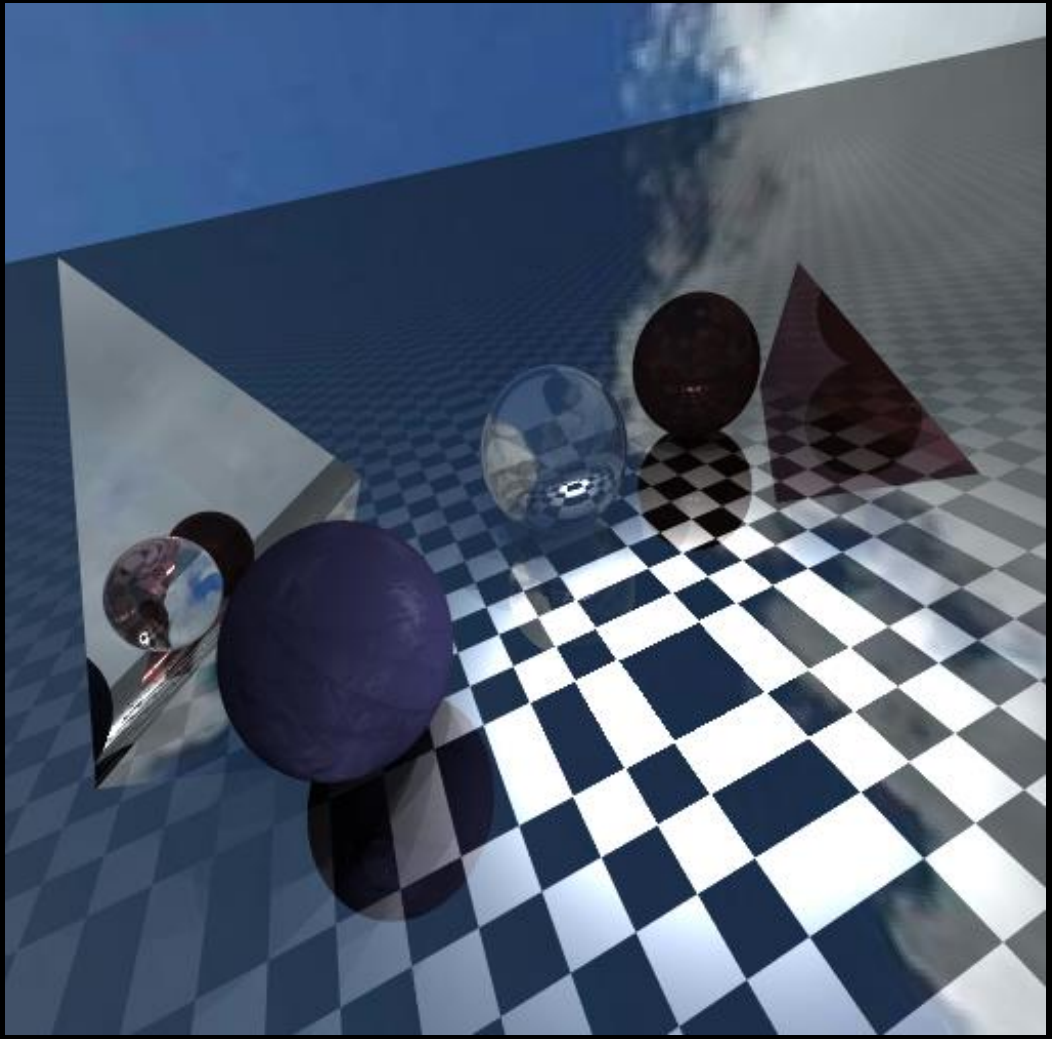
Jacco Bikker & Debabrata Panja - April-July 2017

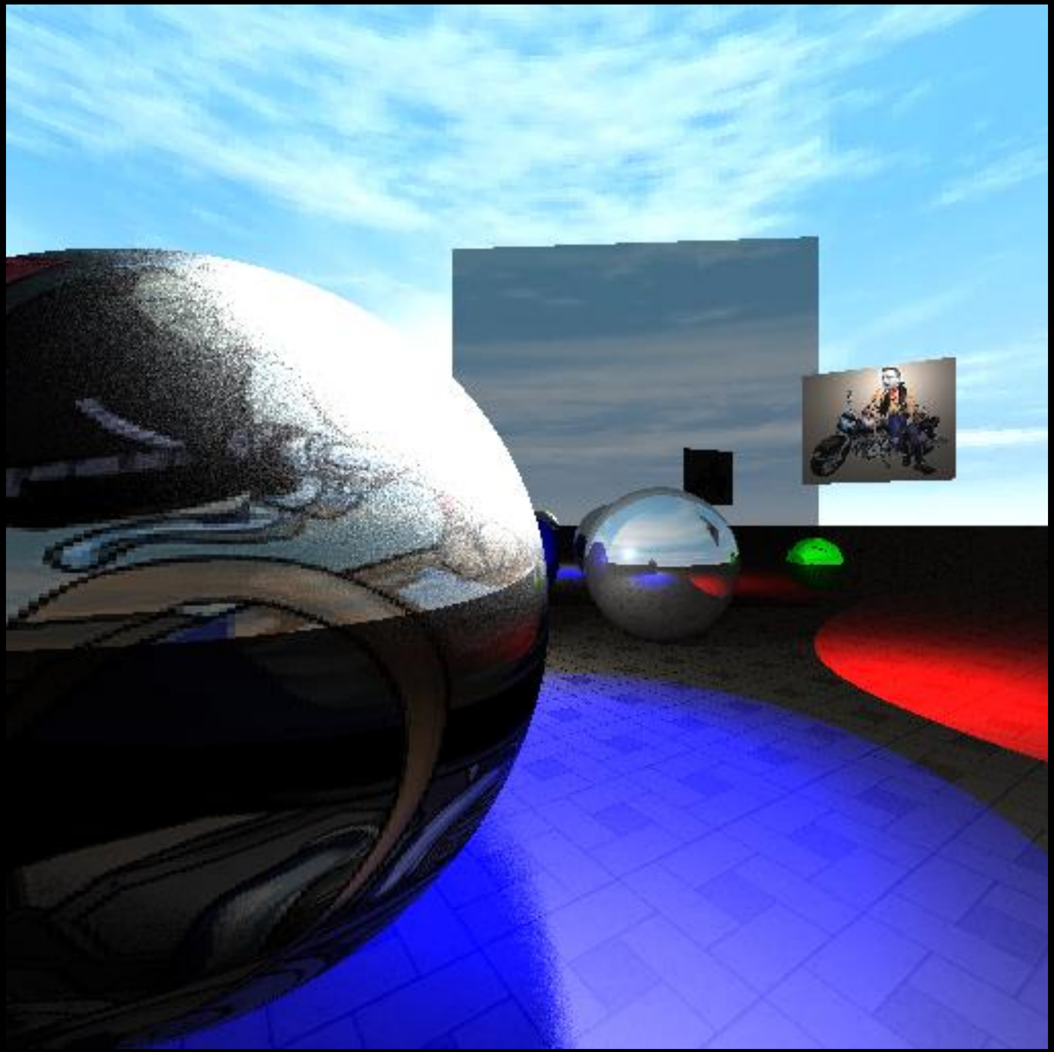
Lecture 10: “Shaders”

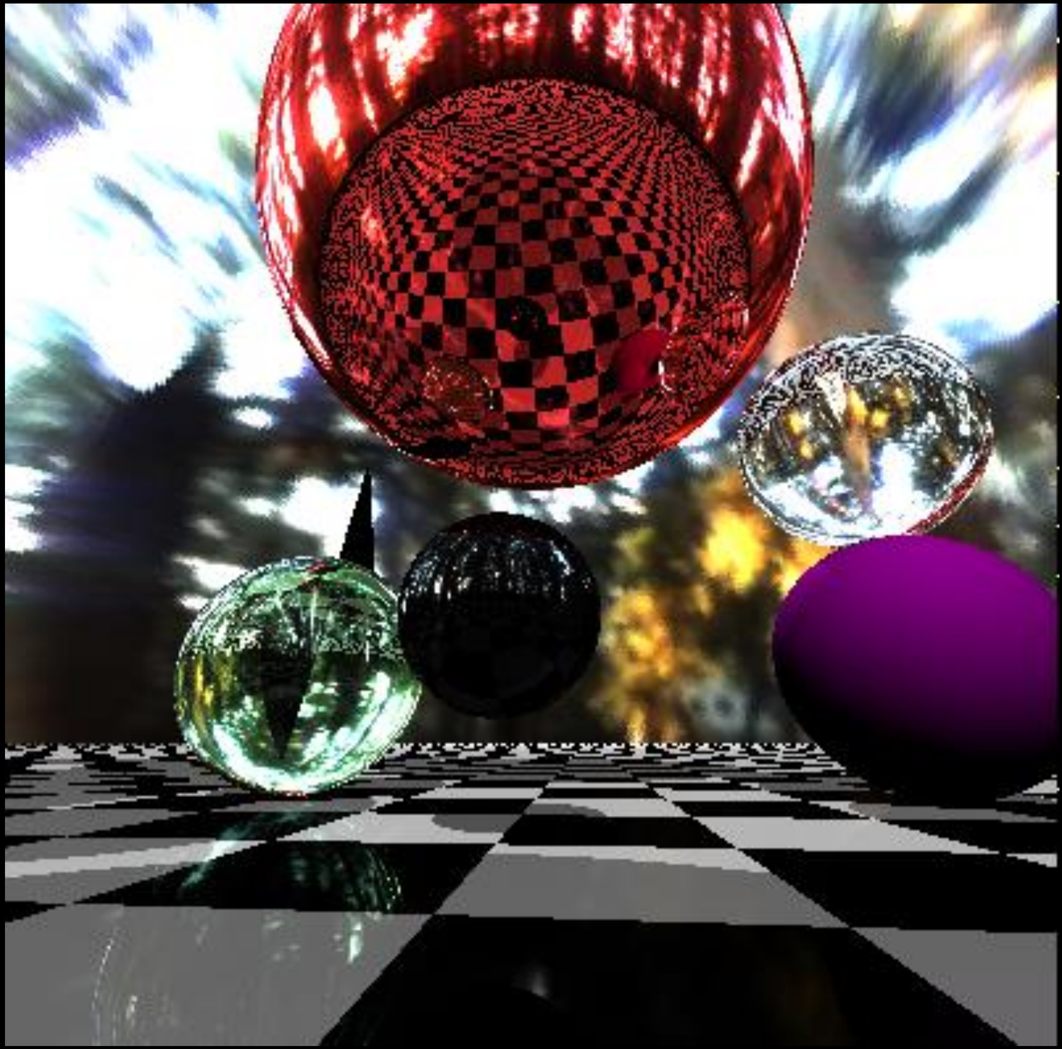
Welcome!

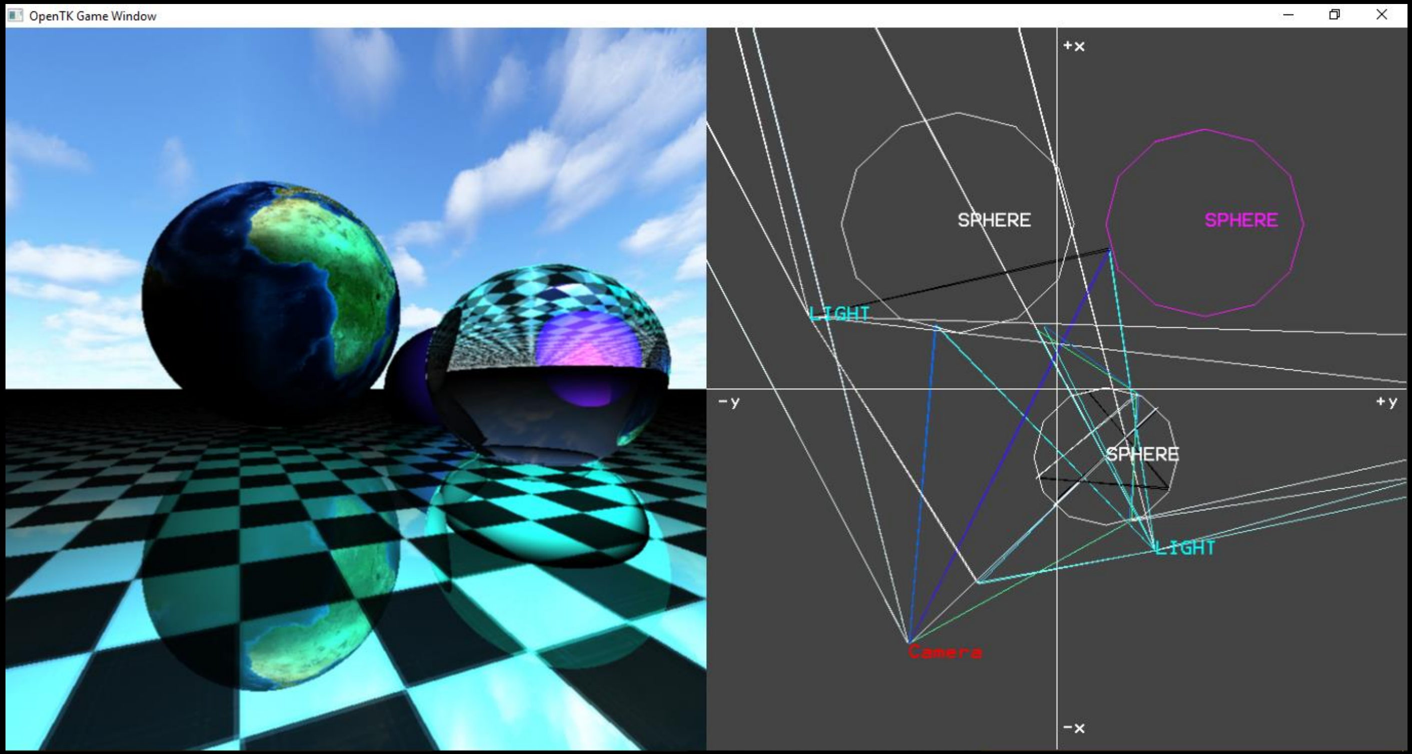




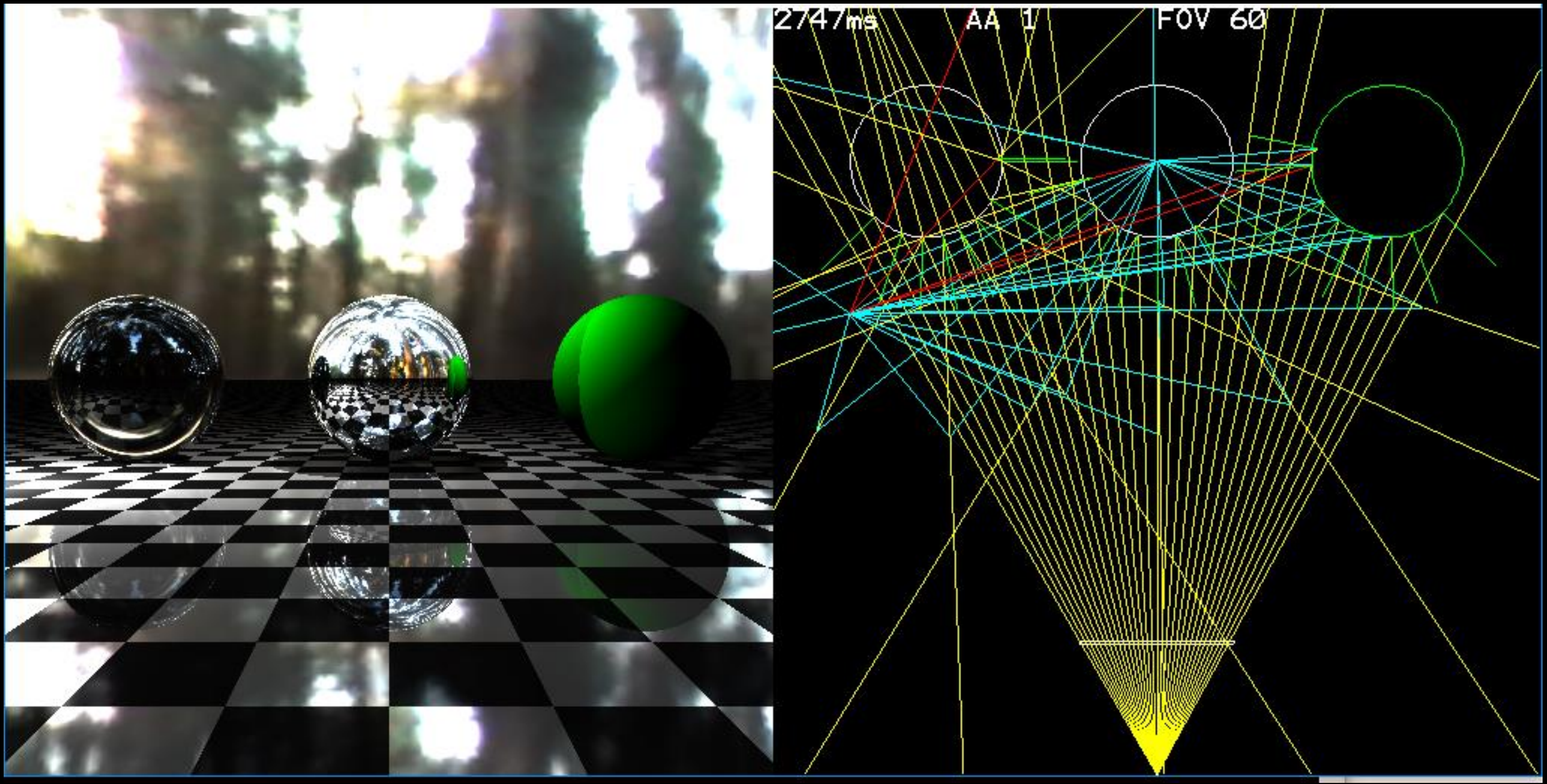


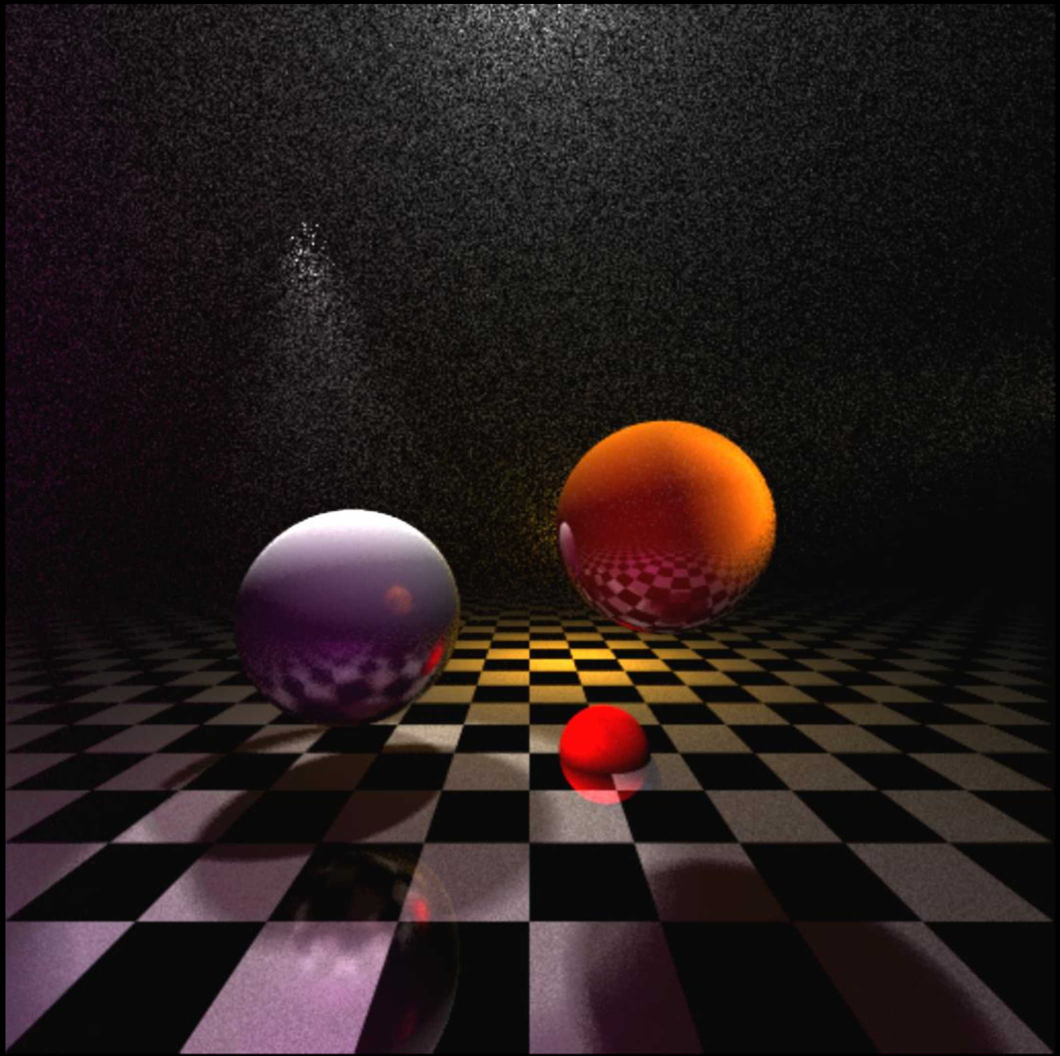


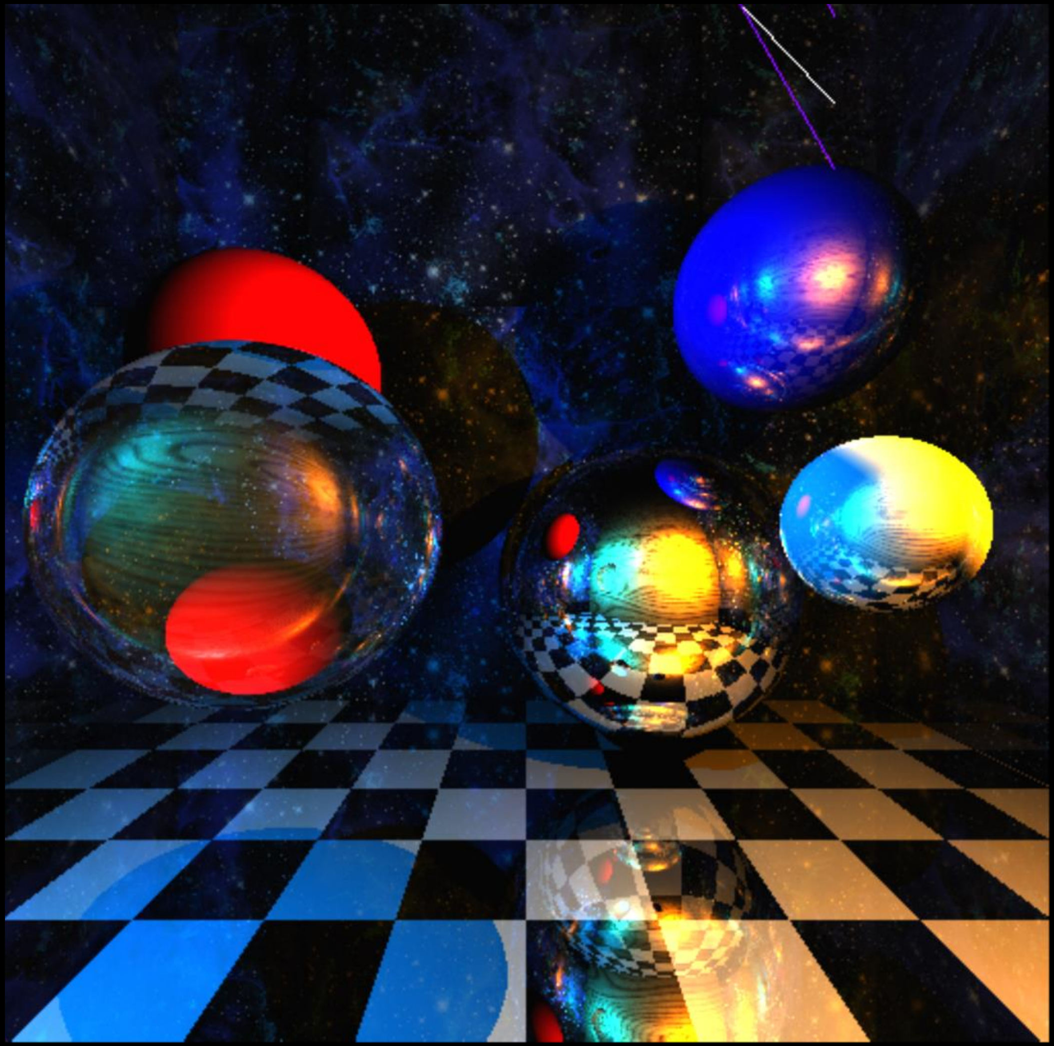



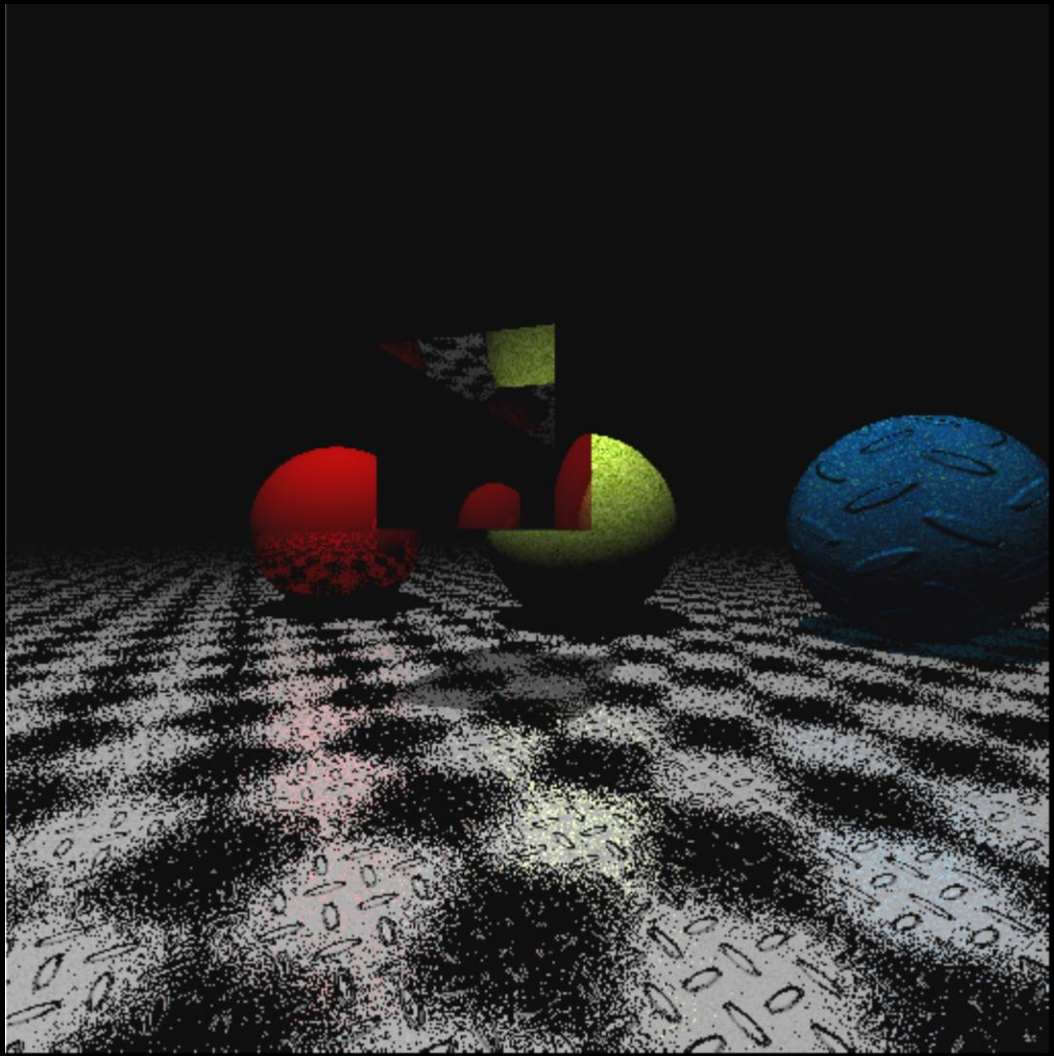


OpenTK Game Window
+x
SPHERE
SPHERE
LIGHT
-y
+y
SPHERE
LIGHT
Camera
-x


2747ms
AA 1
FOV 60







INFOGR2016/17

Today’s Agenda:

- Recap: Diffuse Materials
- The Phong Shading Model
- Environment Mapping
- Normal Mapping
- Rendering Short Fur

Diffuse

Basics of Shading

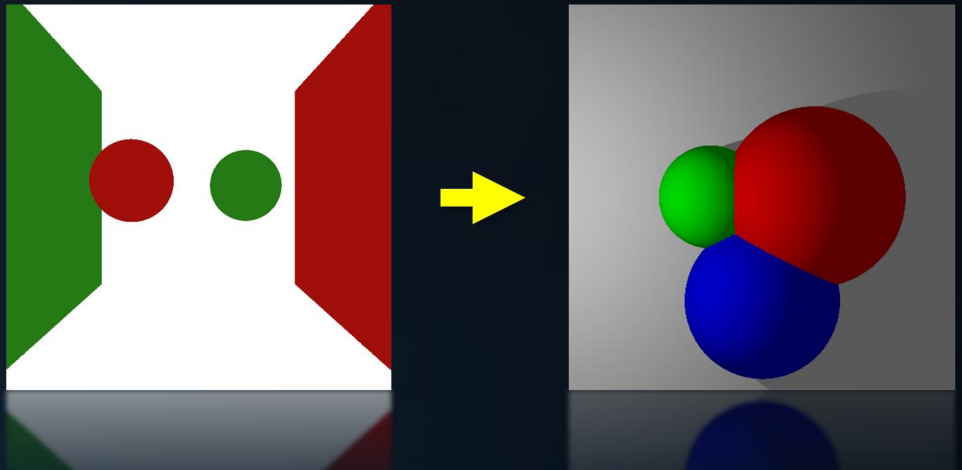
A diffuse material scatters incoming light equally in all directions.

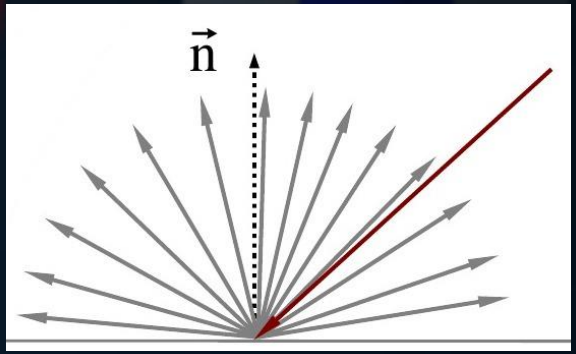
Two aspects to this:

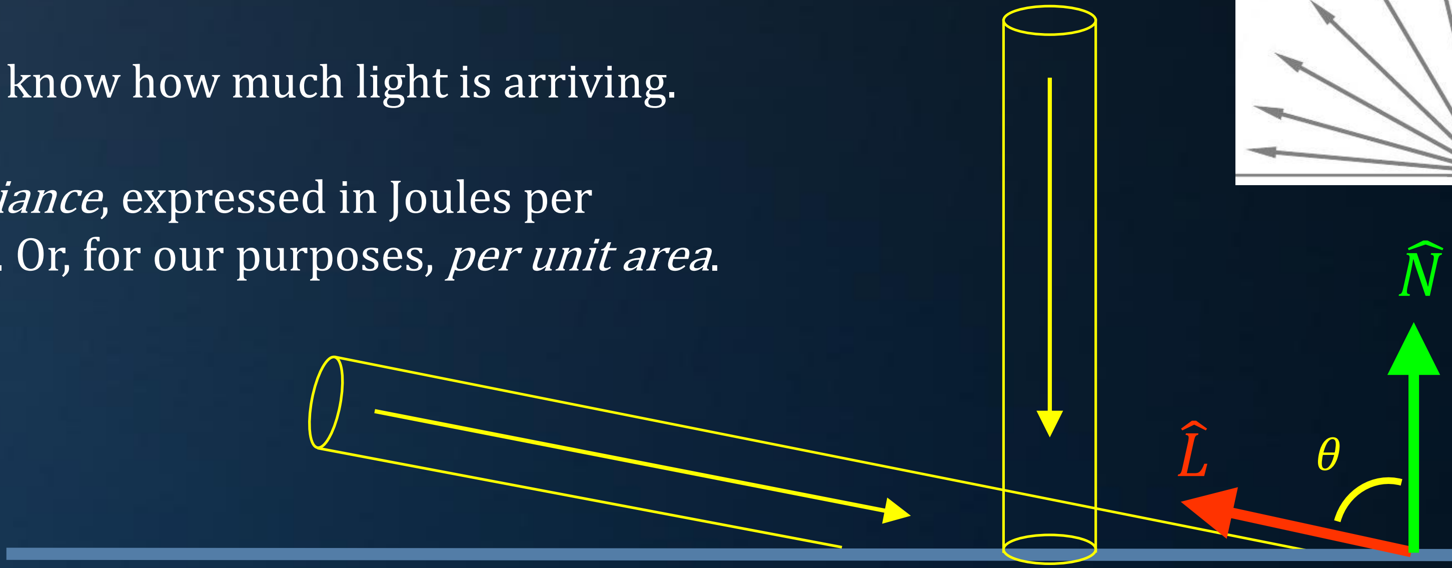
1. Diffuse materials are view-independent.

2. We need to know how much light is arriving.

Arriving: *irradiance*, expressed in Joules per second per m^2. Or, for our purposes, *per unit area*.







$\cos\theta = \hat{N} \cdot \hat{L}$

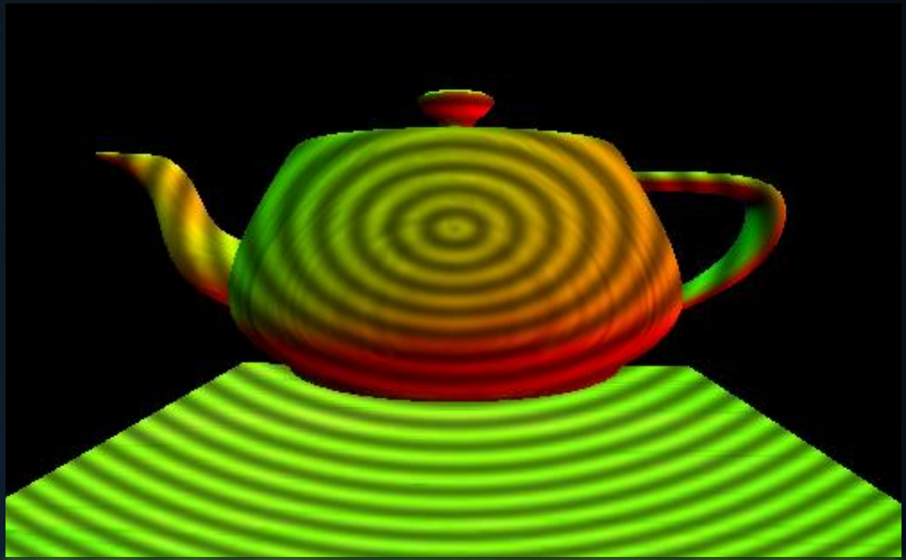
Diffuse

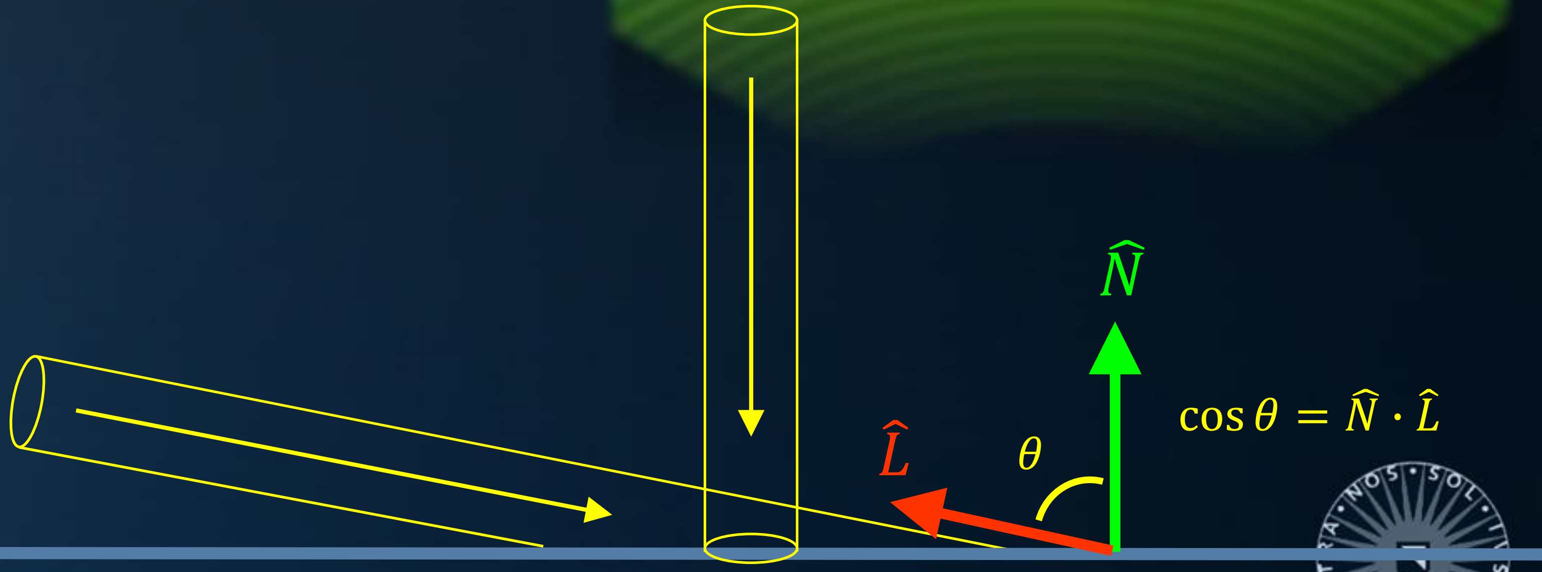
Basics of Shading

So, in the fragment shader:

- Calculate L: $L = lightPos - intersectionPoint$
- Use N: already passed via vertex shader
- Apply attenuation, scale by material color
- Multiply by light color
- Emit fragment color.

But wait…





Diffuse

Basics of Shading

So, in the fragment shader:

- Calculate L: $L = lightPos - intersectionPoint$
- Use N: already passed via vertex shader
- Apply attenuation, scale by material color
- Multiply by light color
- Emit fragment color.

But wait…

We have significant problems:

1. How do we specify a light position
2. In *which space* do we operate?

Ehm…

That one?

```
#version 330

// shader input
in vec2 vUV;
in vec3 vNormal;
in vec3 vPosition;

// shader output
out vec4 normal;
out vec2 uv;
uniform mat4 transform;

// vertex shader
void main()
{
    // transform vertex using supplied matrix
    gl_Position = transform * vec4( vPosition, 1.0 );

    // forward normal and uv coordinate
    normal = transform * vec4( vNormal, 0.0f );
    uv = vUV;
}
```

model space

model space
to
screen space

Diffuse

Spaces

Default matrix in game.cs:

```
Matrix4 transform = Matrix4.CreateFromAxisAngle( new Vector3( 0, 1, 0 ), a );
transform *= Matrix4.CreateTranslation( 0, -4, -15 );
transform *= Matrix4.CreatePerspectiveFieldOfView( 1.2f, 1.3f, .1f, 1000 );
```

This produces:

- a teapot that spins around it’s pivot
- a camera located at (0, 4, 15) *or* the teapot spins at (0, -4, 15), camera is at (0, 0, 0).

The last line adds perspective.

➔ We need a *‘base system’* in which we can define a light position: *world space*.

Diffuse

Spaces

Getting model space coordinates to world space:

```
Matrix4 transform = Matrix4.CreateFromAxisAngle( new Vector3( 0, 1, 0 ), a );
Matrix4 toWorld = transform;
transform *= Matrix4.CreateTranslation( 0, -4, -15 );
transform *= Matrix4.CreatePerspectiveFieldOfView( 1.2f, 1.3f, .1f, 1000 );
```

We need some additional changes now:

```
public void Render(
        Shader shader,
        Matrix4 transform,
        Matrix4 toWorld,
        Texture texture
)
{
        ...
}
```

Diffuse

Changes

The vertex shader now takes two matrices:

```
// transforms
uniform mat4 transform;     // full transform: model space to screen space
uniform mat4 toWorld;       // model space to world space
```

...and uses them:

```
gl_Position = transform * vec4( vPosition, 1.0 );
worldPos = toWorld * vec4( vPosition, 1.0f );
normal = toWorld * vec4( vNormal, 0.0f );
```

Diffuse

Changes

The shader class needs to know about the two matrices:

```
public int uniform_mview;
public int uniform_2wrld;

...

uniform_mview = GL.GetUniformLocation( programID, "transform" );
uniform_2wrld = GL.GetUniformLocation( programID, "toWorld" );
```

And the mesh class needs to pass both to the shader:

```
// pass transforms to vertex shader
GL.UniformMatrix4( shader.uniform_mview, false, ref transform );
GL.UniformMatrix4( shader.uniform_2wrld, false, ref toWorld );
```

Diffuse

Changes

The new fragment shader, complete:

```
#version 330
in vec2 uv;                  // interpolated texture coordi
in vec4 normal;              // interpolated normal, world
in vec4 worldPos;            // world space position of frag
uniform sampler2D pixels;    // texture sampler
out vec4 outputColor;        // shader output
uniform vec3 lightPos;       // light position in world space
void main()                  // fragment shader
{
    vec3 L = lightPos - worldPos.xyz;
    float dist = L.length();
    L = normalize( L );
    vec3 lightColor = vec3( 10, 10, 8 );
    vec3 materialColor = texture( pixels, uv ).xyz;
    float attenuation = 1.0f / (dist * dist);
    outputColor = vec4( materialColor * max( 0.0f, dot( L, normal.xyz ) ) *
         attenuation * lightColor, 1 );
}
```

In game.cs, Init():

```
// set the light
int lightID = GL.GetUniformLocation(
    shader.programID,
    "lightPos"
);
GL.UseProgram( shader.programID );
GL.Uniform3(
    lightID,
    0.0f, 10.0f, 0.0f
);
```

Diffuse

Today’s Agenda:

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- The Phong Shading Model
- Environment Mapping
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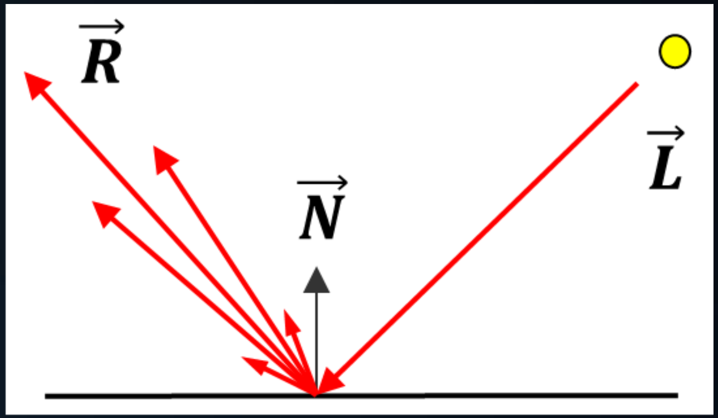
- Rendering Short Fur

Phong



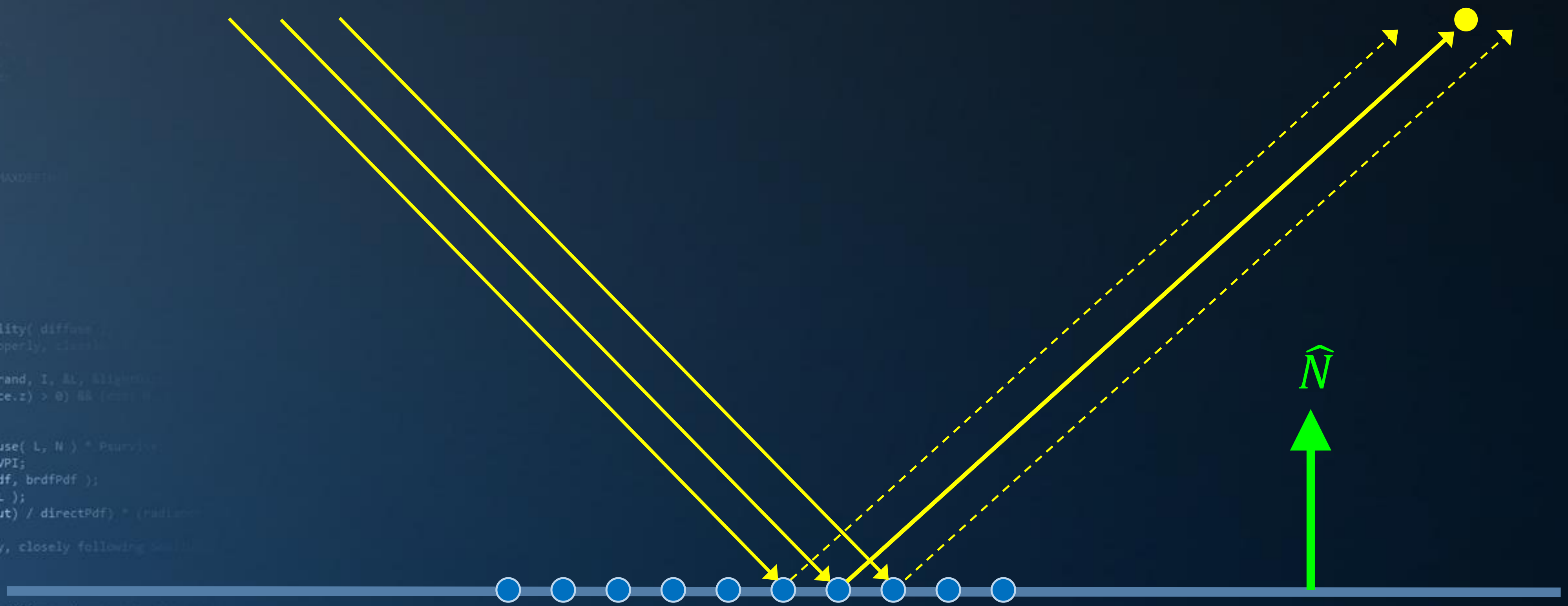
Glossy Materials

A glossy material reflects, but the reflection is somewhat fuzzy:

Using a ray tracer we achieve this effect by sending multiple rays in directions close to the reflection vector $\hat{R}$.

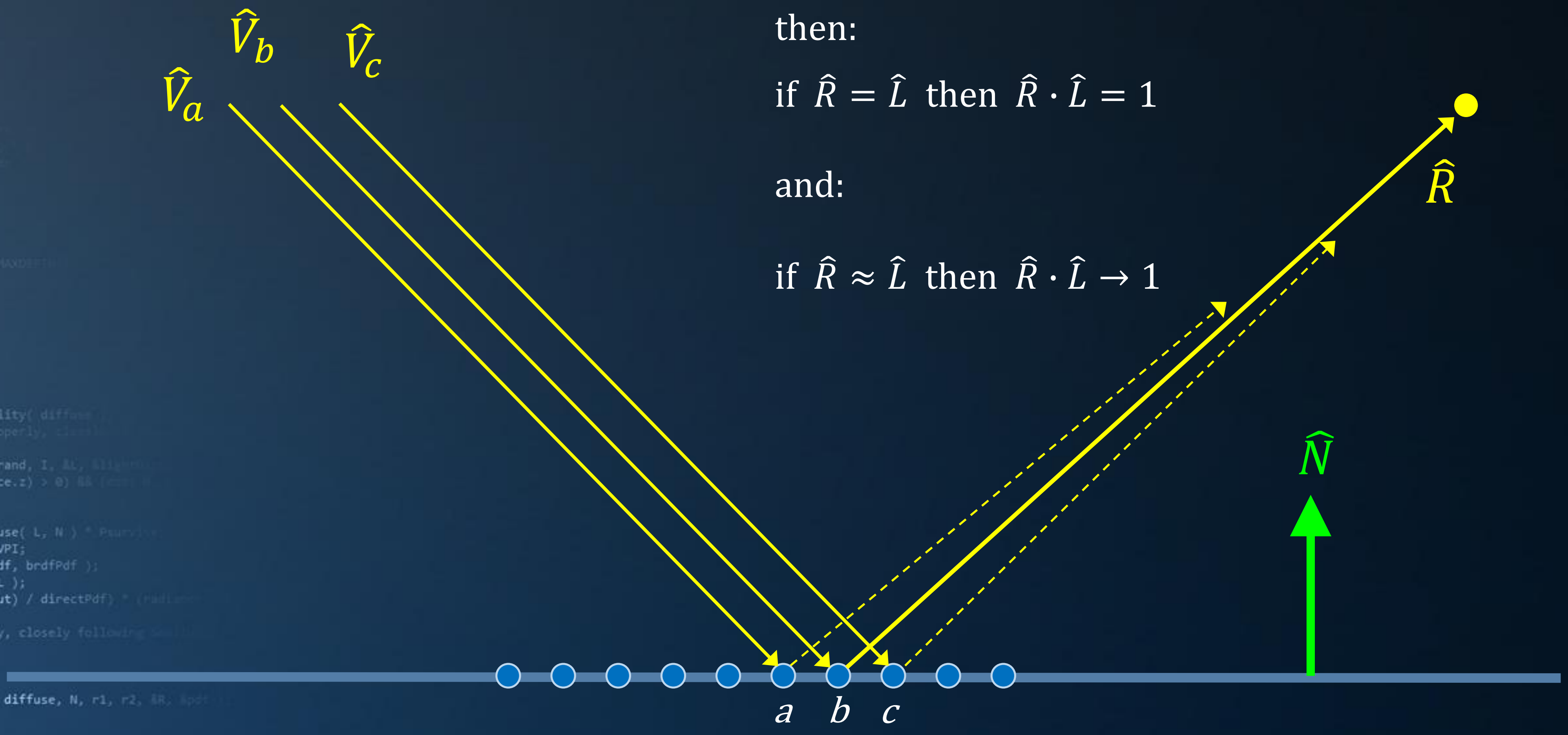
Phong

Glossy Materials



Phong

Glossy Materials



Let:

$\hat{L}$ be a vector from the fragment position b to the light;
$\hat{R}$ be the vector $\hat{V}_b$ reflected in the plane with normal $\hat{N}$

then:

if $\hat{R} = \hat{L}$ then $\hat{R} \cdot \hat{L} = 1$

and:

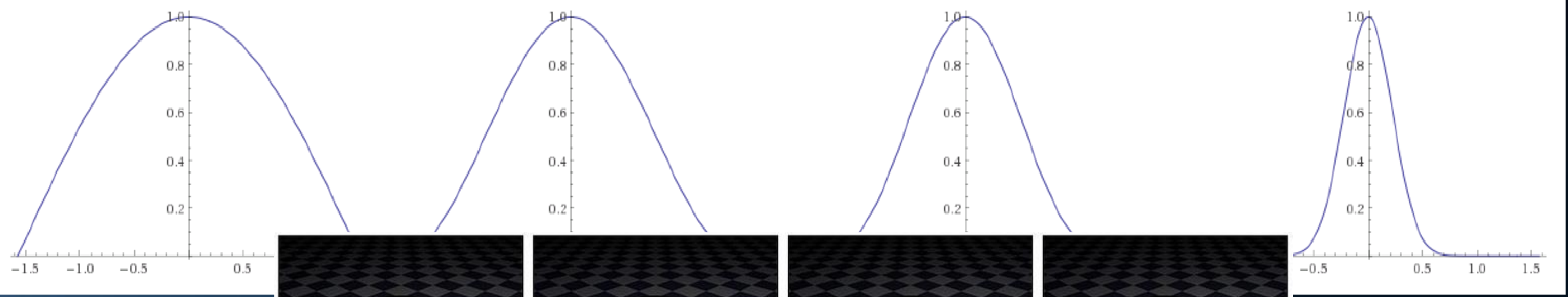
if $\hat{R} \approx \hat{L}$ then $\hat{R} \cdot \hat{L} \rightarrow 1$

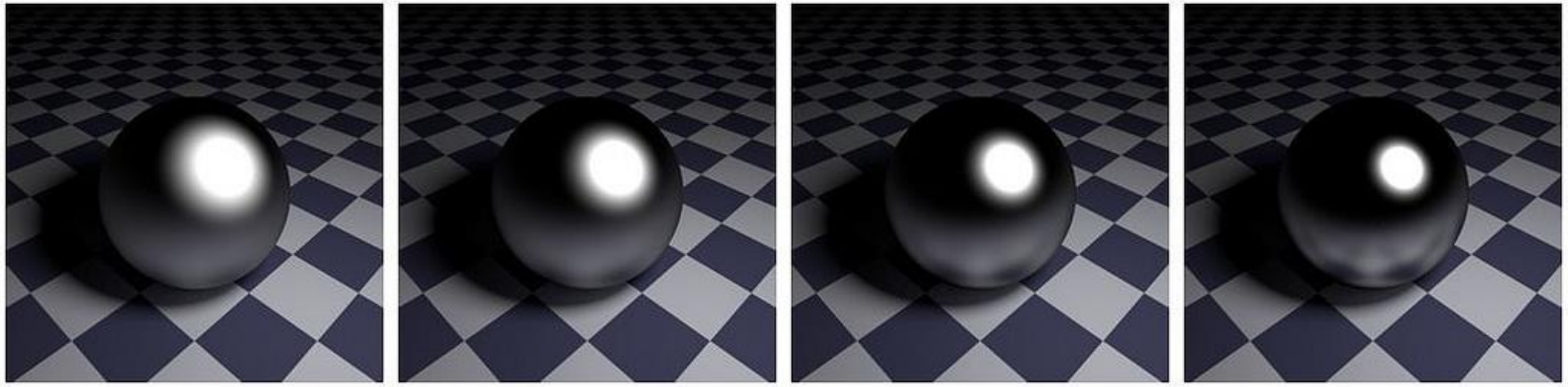
Phong

Glossy Materials

“Locations near b receive almost as much light as b.”

But how much? $\left(\hat{L} \cdot \hat{V}\right)^{\alpha}$





Phong

The Full Phong

$$M_{phong} = c_{ambient} + c_{diff}\left(\vec{N} \cdot \vec{L}\right)L_{diff} + c_{spec}(\vec{L} \cdot \vec{R})^{\alpha} L_{spec}$$

The Phong material model is a combination of:

- ‘Specular’ illumination: $(\vec{L} \cdot \vec{R})^{\alpha}$, times the ‘specular color’ of the light, times the ‘specular color’ of the material;
- Diffuse illumination: $\left(\vec{N} \cdot \vec{L}\right)$, times the ‘diffuse color’ of the light, times the ‘diffuse color’ of the material;
- An ‘ambient color’.

Phong


Diffuse Lighting used in
Half-Life 2
+
Specular Lighting
=
High Quality Lighting in
Half-Life 2: Episode One

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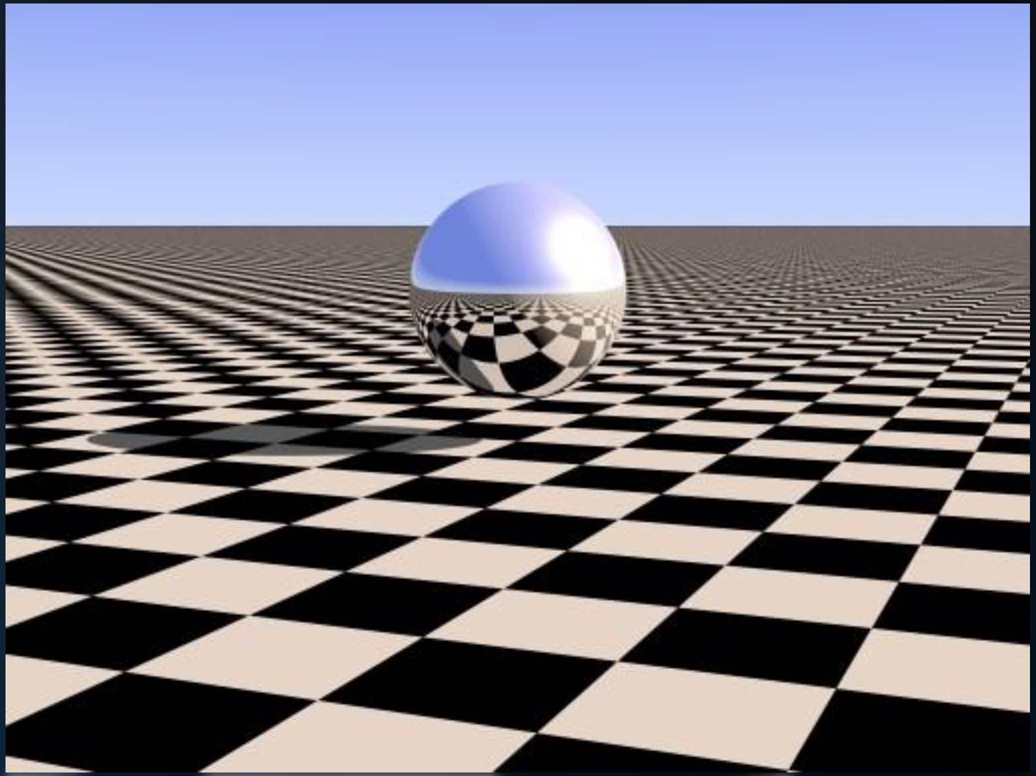
Mirrors

Reflections

Reflections in a ray tracer are easy:

$$\vec{R} = \vec{L} - 2(\vec{L} \cdot \vec{N})\vec{N}$$

But what about rasterizers?



Mirrors

Mirrors

Planar Reflections

We can fake reflections in a rasterizer by duplicating the scene:

The mirror is not really there; it’s just a hole through which we see a copy of the scene.

Mirrors

Mirrors

Environment Mapping

Reflections on complex surfaces are faked using an environment map.

This is done exactly as in a ray tracer:

- at the fragment position, we have $\hat{V}$ and $\hat{N}$;
- based on these we calculate the reflected vector $\hat{R}$;
- we use $\hat{R}$ to look up a value in the skydome texture.

Limitations:

- we will not reflect anything but the skydome;
- the reflection is static.

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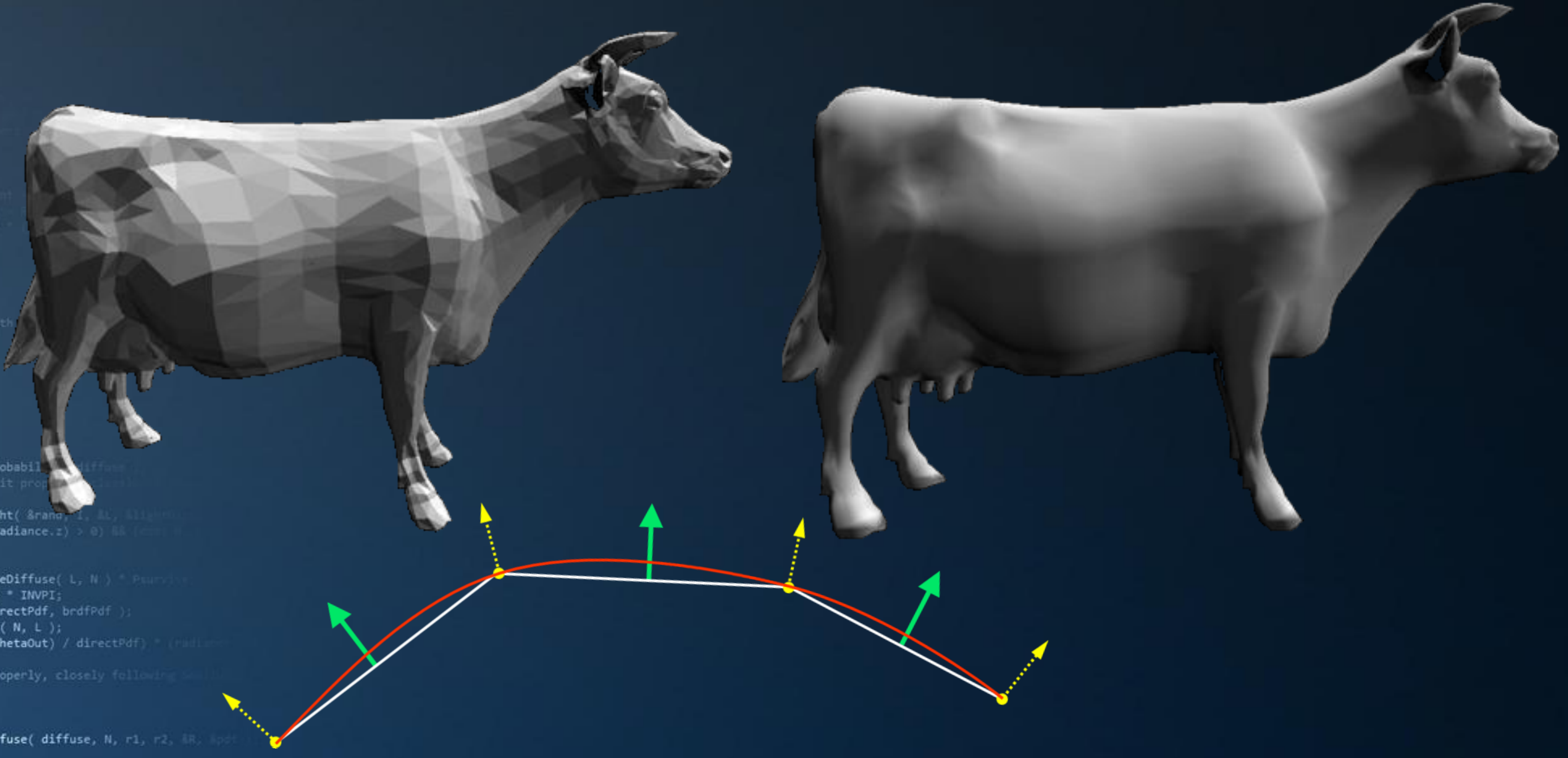
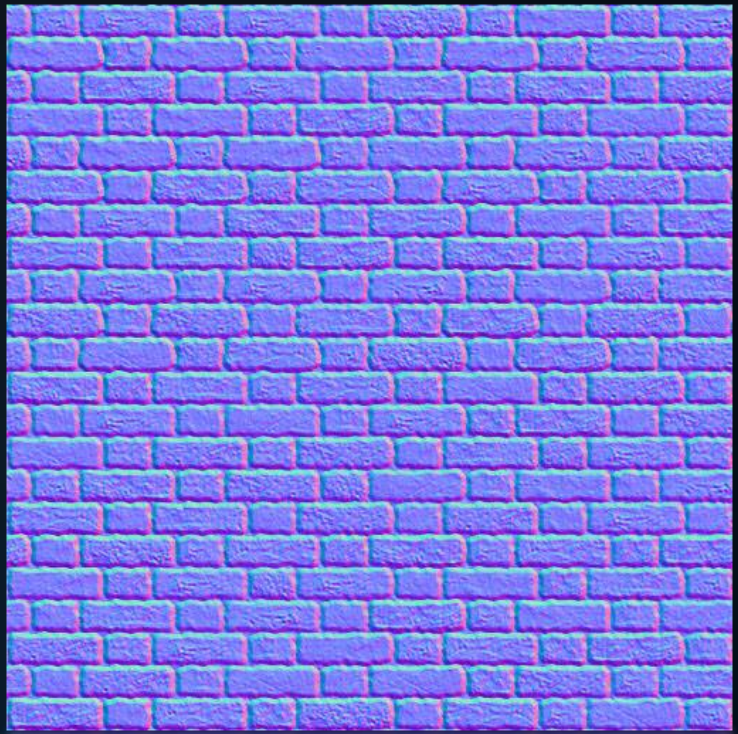
Bumps

Recap: Normal Interpolation



Bumps



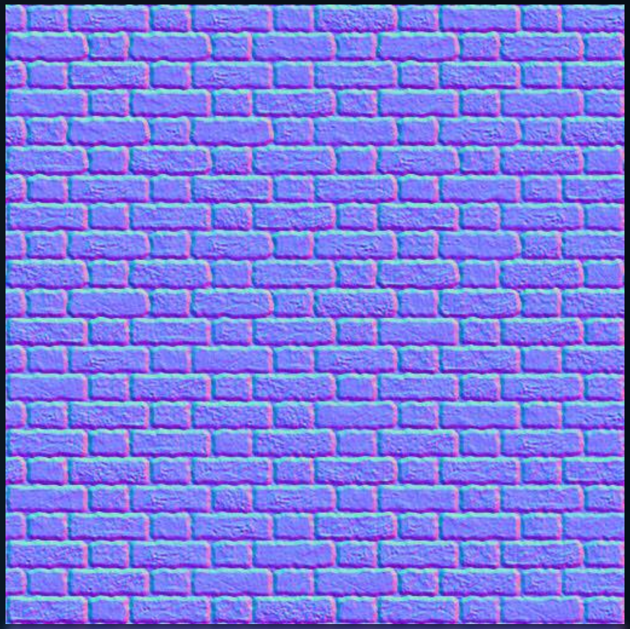
Normal Maps

A normal map is similar to a texture:

- we use textures to lookup a color at a particular position on a mesh;
- we use normal to lookup a normal at a particular position.

Normal maps generally store normals in *tangent space*.

Bumps



Normal Map Data

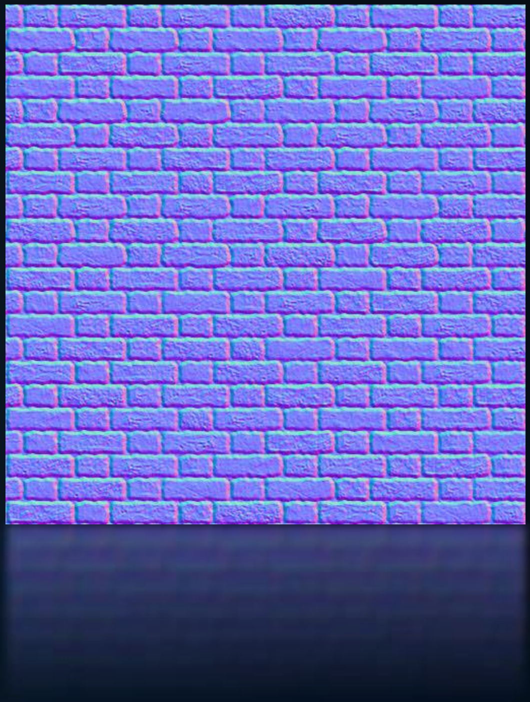
A normal map stores 2 or 3 components per texel.

For 3 components: $x, y, z \ \in [0..255]$.

To get this to the correct range:

- Cast to float
- Divide by 128 ➔ $x, y, z \ \in [0..2]$
- Subtract 1 ➔ $x, y, z \ \in [-1..1]$

Bumps



Normal Map Data

A normal map stores 2 or 3 components per texel.

For 2 components: $x, y \in [0..255]$.

To reconstruct the normal, we first apply the same conversion as we did for three components. Then:

$$\sqrt{x^2 + y^2 + z^2} = 1$$

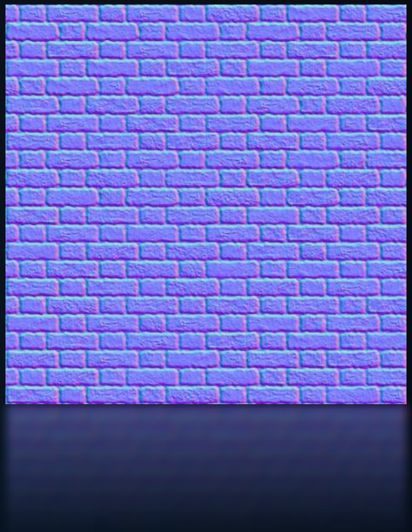
$$x^2 + y^2 + z^2 = 1$$

$$z^2 = 1 - (x^2 + y^2)$$

$$z = \pm\sqrt{1 - (x^2 + y^2)}$$

$$z = \sqrt{1 - (x^2 + y^2)}$$

Bumps



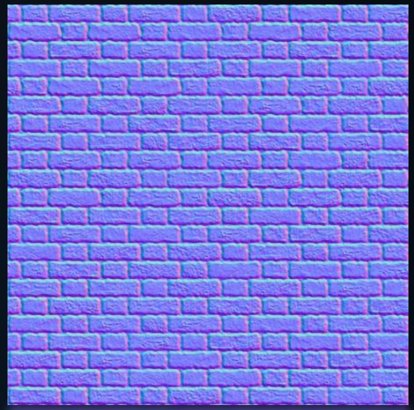
Tangent Space

Things are easy when $x = \begin{pmatrix}1\\0\\0\end{pmatrix}$, $y = \begin{pmatrix}0\\1\\0\end{pmatrix}$ and $z = \begin{pmatrix}0\\0\\1\end{pmatrix}$:

$$N = M_x x + M_y y + M_z z$$

$$= M_x \begin{pmatrix}1\\0\\0\end{pmatrix} + M_y \begin{pmatrix}0\\1\\0\end{pmatrix} + M_z \begin{pmatrix}0\\0\\1\end{pmatrix} = \begin{pmatrix}M_x\\M_y\\M_z\end{pmatrix}$$

Bumps



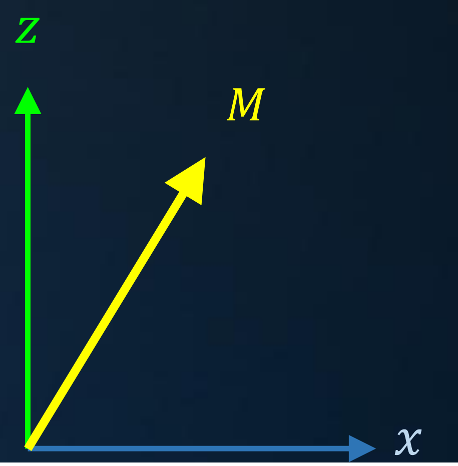
Tangent Space

Things are still easy for arbitrary x, y and z :

$$N = M_x x + M_y y + M_z z$$

Obtaining this x, y and z:

- $z =$ (interpolated) surface normal
- x is perpendicular to z
- y is perpendicular to z and x



See Crytek for details*.

http://docs.cryengine.com/display/SDKDOC4/Tangent+Space+Normal+Mapping
https://fenix.tecnico.ulisboa.pt/downloadFile/845043405449073/Tangent%20Space%20Calculation.pdf

Bumps

Bumps

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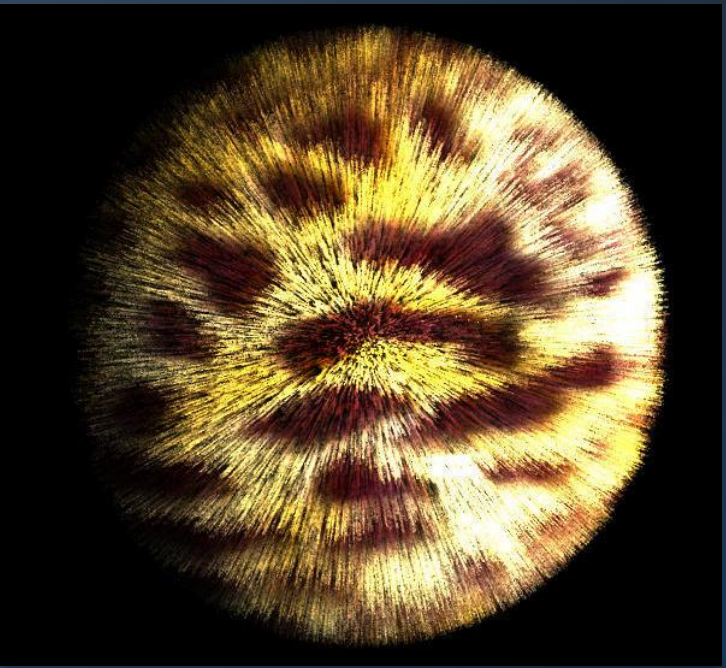
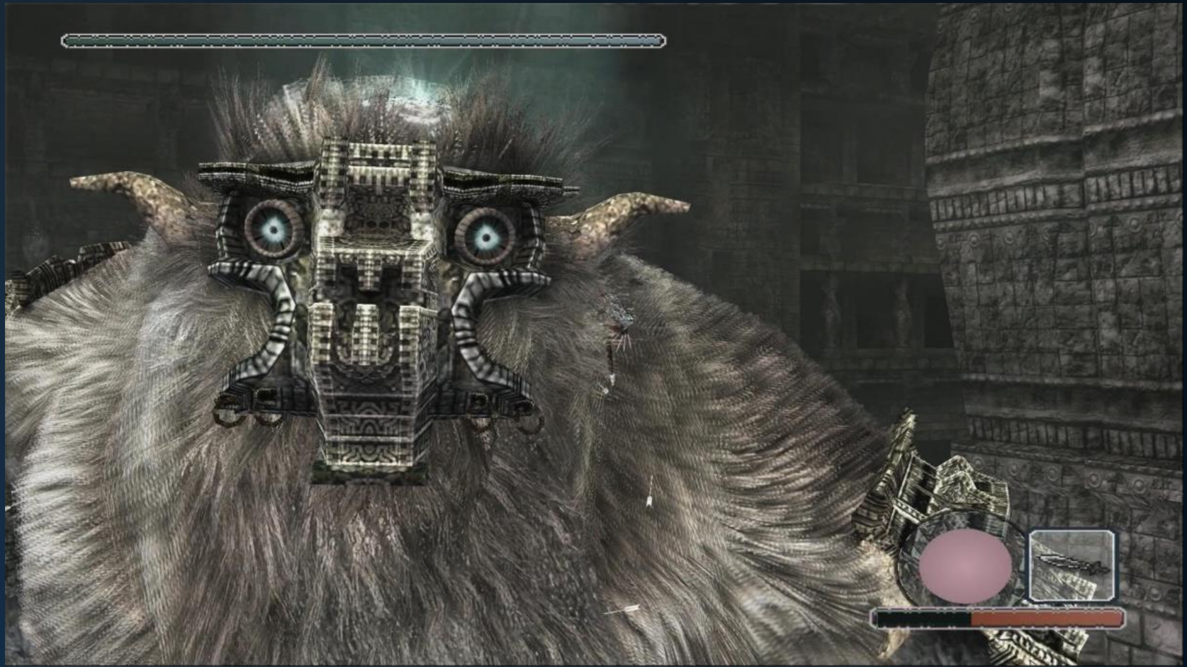
Fur

Fur, Grass etc.



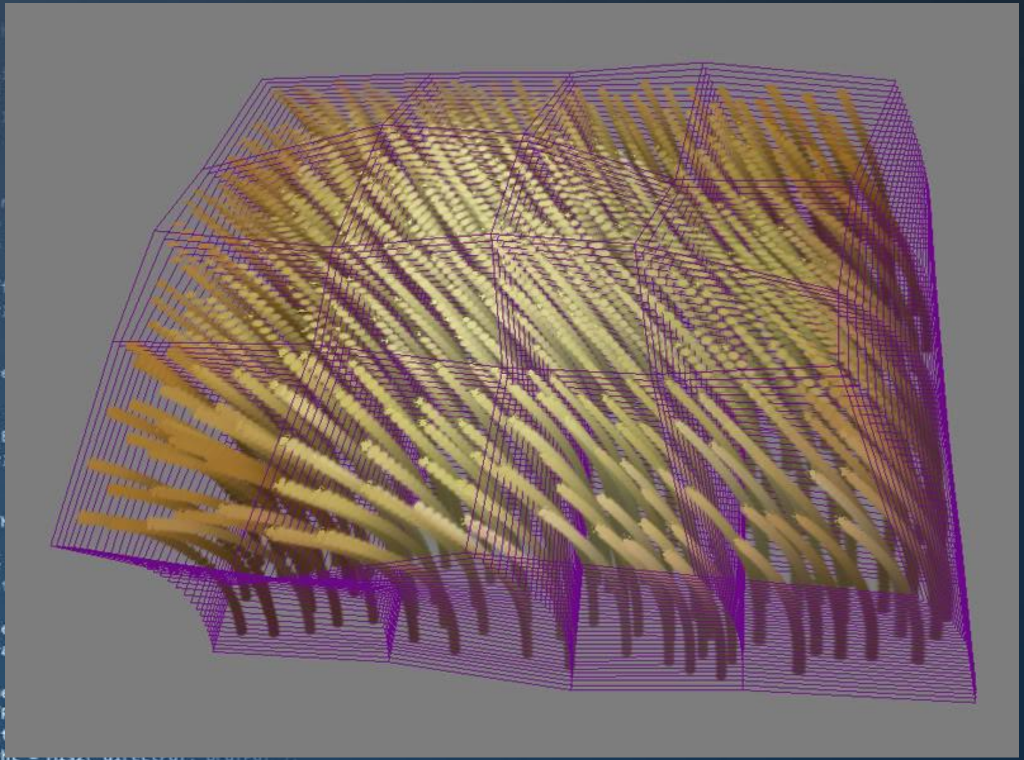
Fur

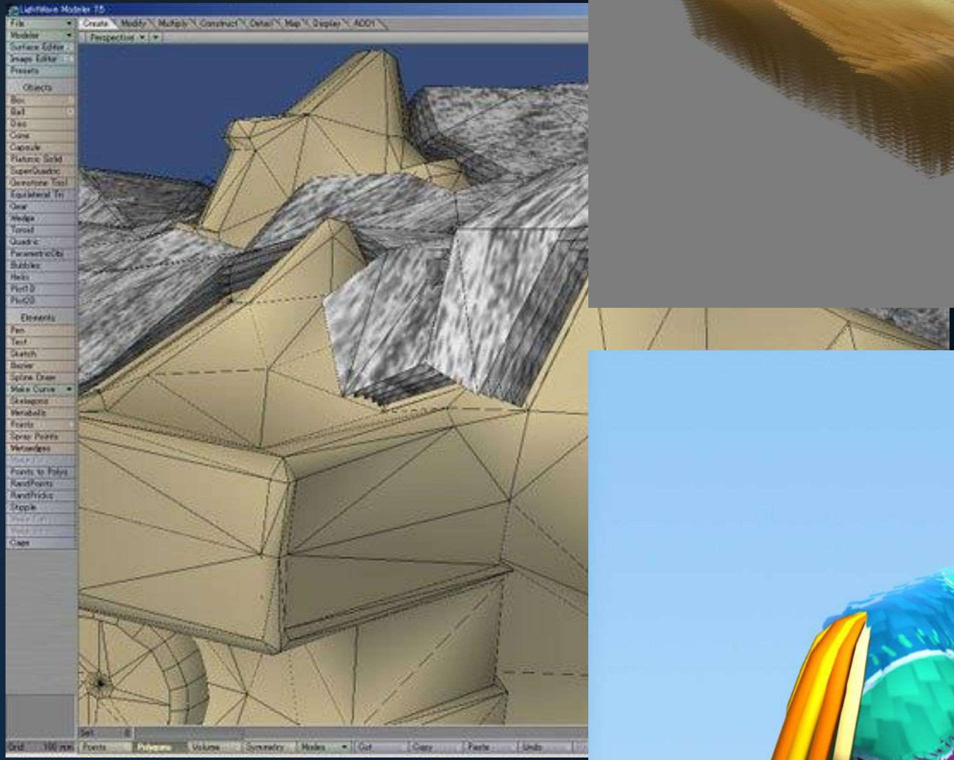
Fur, Grass etc.

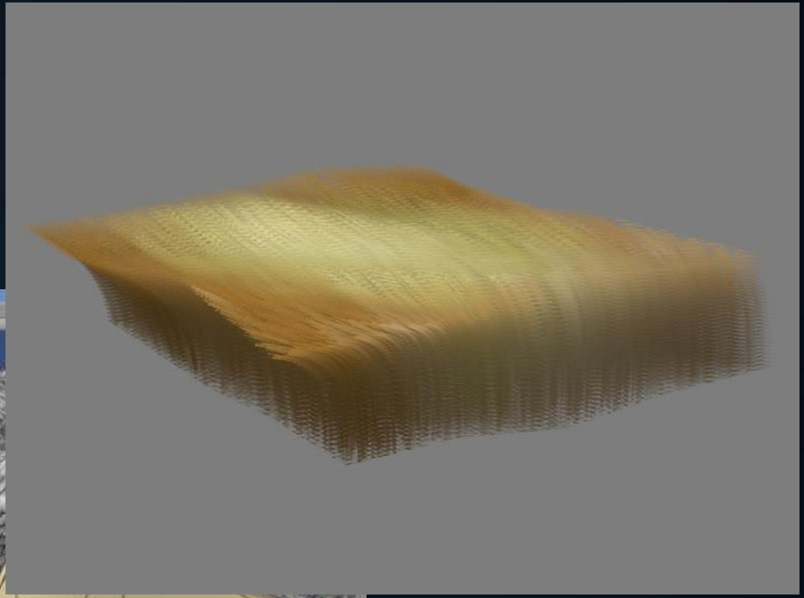


Fur

Fur, Grass etc.

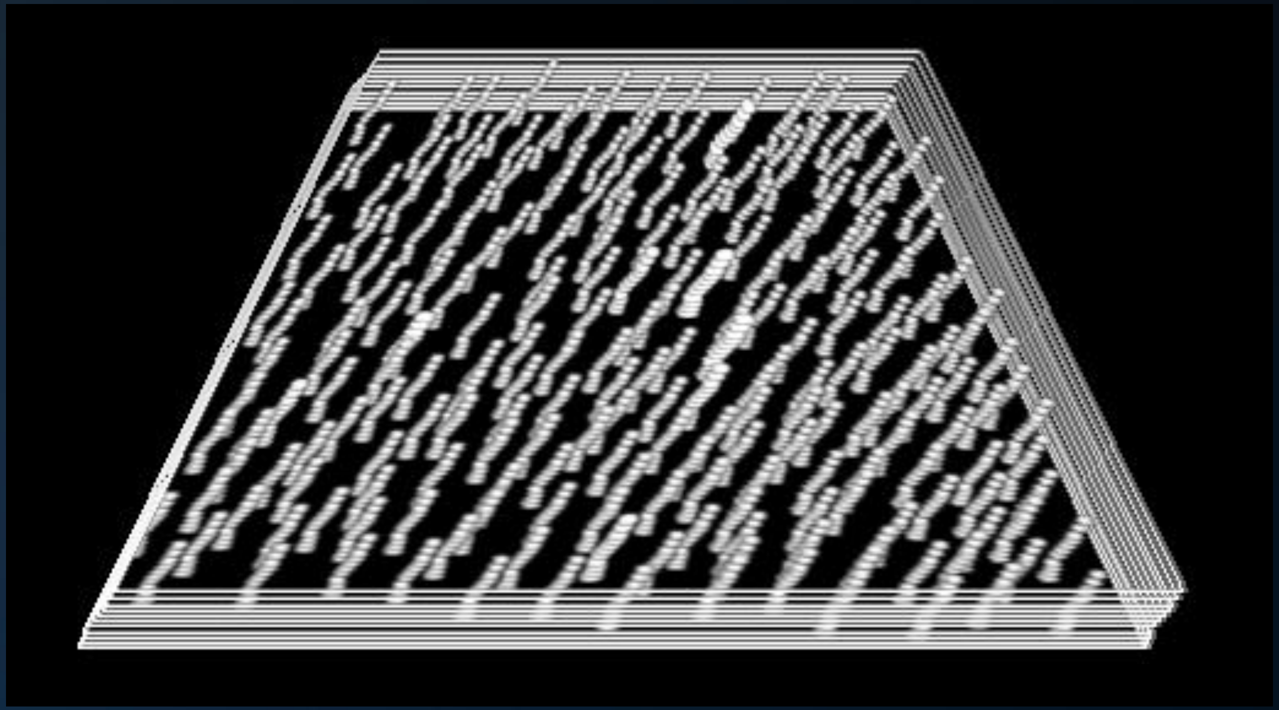






Fur

Fur, Grass etc.



Fur

Fur, Grass etc.

```
#version 330

...

// shell offset
uniform float shellOffset;

// vertex shader
void main()
{
    gl_Position = transform * vec4( vPosition + shellOffset * vNormal, 1.0 );
    worldPos = toWorld * vec4( vPosition + shellOffset * vNormal, 1.0f );
    normal = toWorld * vec4( vNormal, 0.0f );
    uv = vUV;
}
```

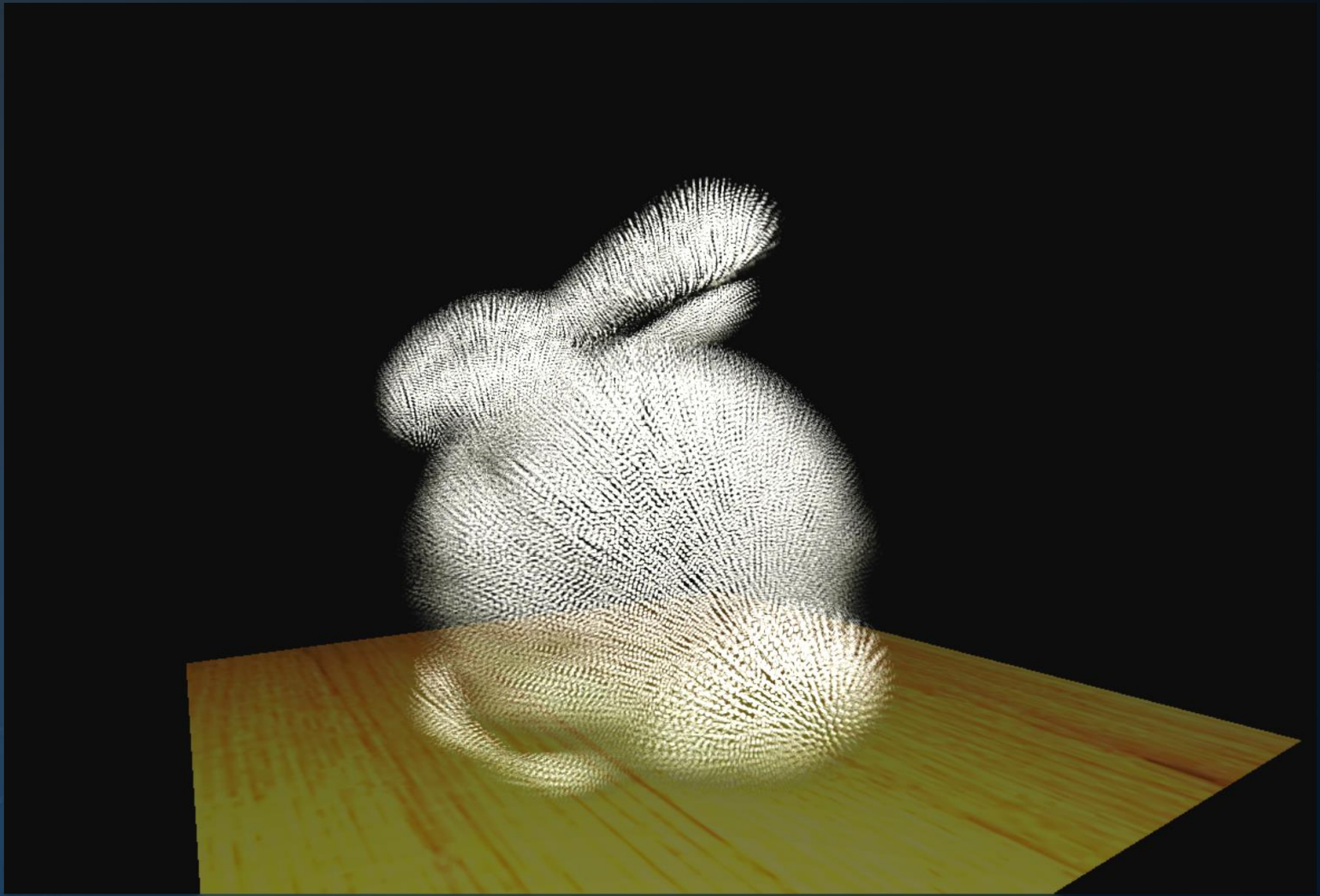
Fur

Fur, Grass etc.

In game.cs:

```
for( int i = 0; i < 30; i++ )
{
    GL.UseProgram( shader.programID );
    GL.Uniform1( offsetID, (float)i * 0.02f );
    mesh.Render( shader, prevMat[19 - i / 4], prevWld[19 - i / 4], fur );
}
```

Fur



INFOGR – Computer Graphics

Jacco Bikker & Debabrata Panja - April-July 2017

END OF lecture 10: "Shaders"

Next lecture: "Visibility"