ROYAL INSTITUTE OF TECHNOLOGY

DH2323 DGI16

INTRODUCTION TO COMPUTER GRAPHICS AND INTERACTION

LIGHTING AND SHADING

Christopher Peters

CST, KTH Royal Institute of Technology, Sweden

chpeters@kth.se

http://kth.academia.edu/ChristopherEdwardPeters

Based on DGI12 notes by Carl Henrik Ek

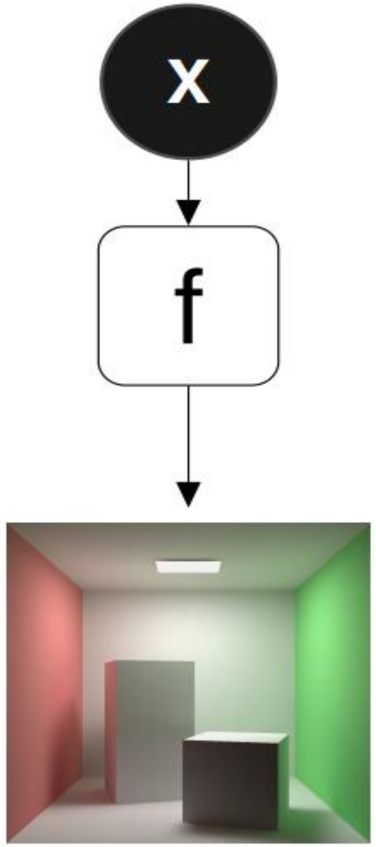
Image Synthesis

In computer graphics, create images based on a *model*

Recall:

An underlying process generates observations

Can control generation through parameters



Nice Results

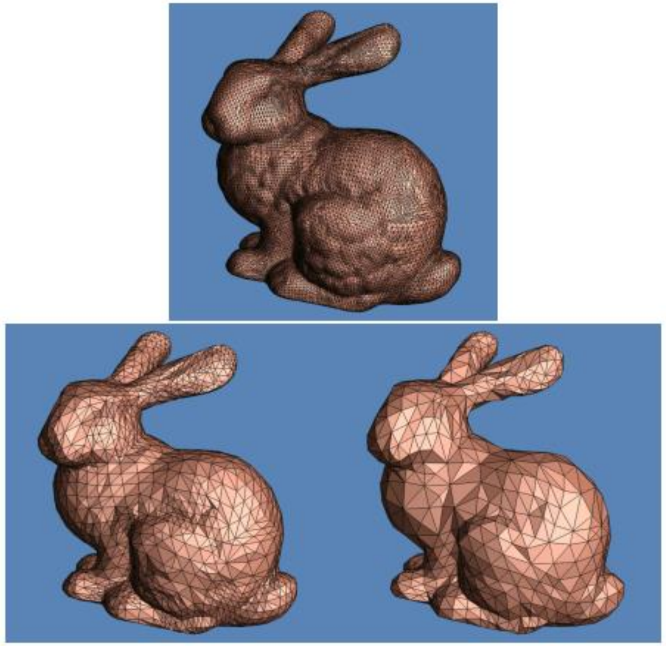
"Distant Shores" by Christoph Gerber

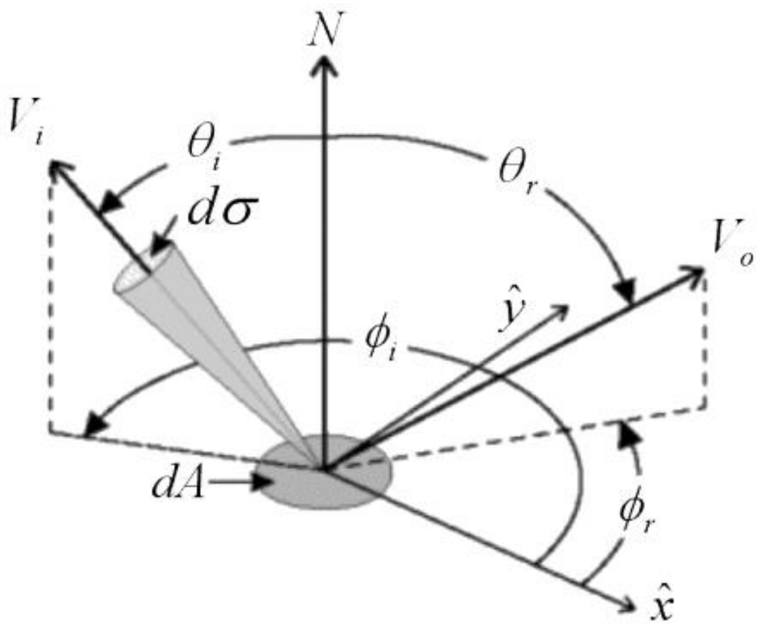
"Christmas Baubles" by Jaime Vives Piqueres

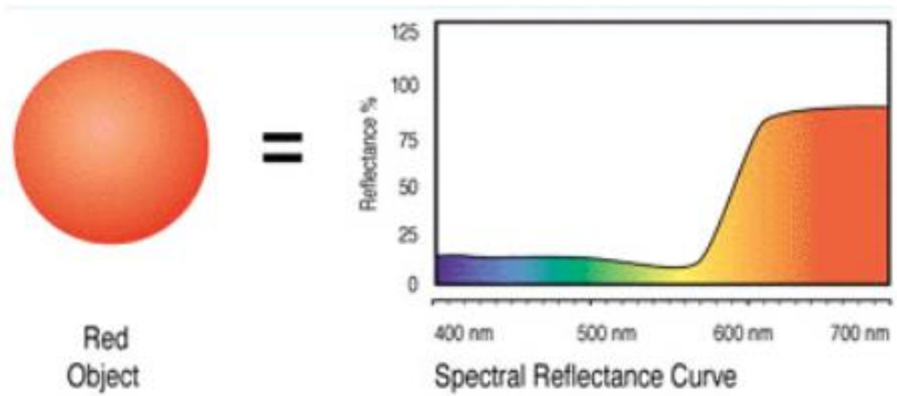
"Still with Bolts" by Jaime Vives Piqueres

Some Constituents I

- Light
- Geometry
- Surface properties
- Anything else?

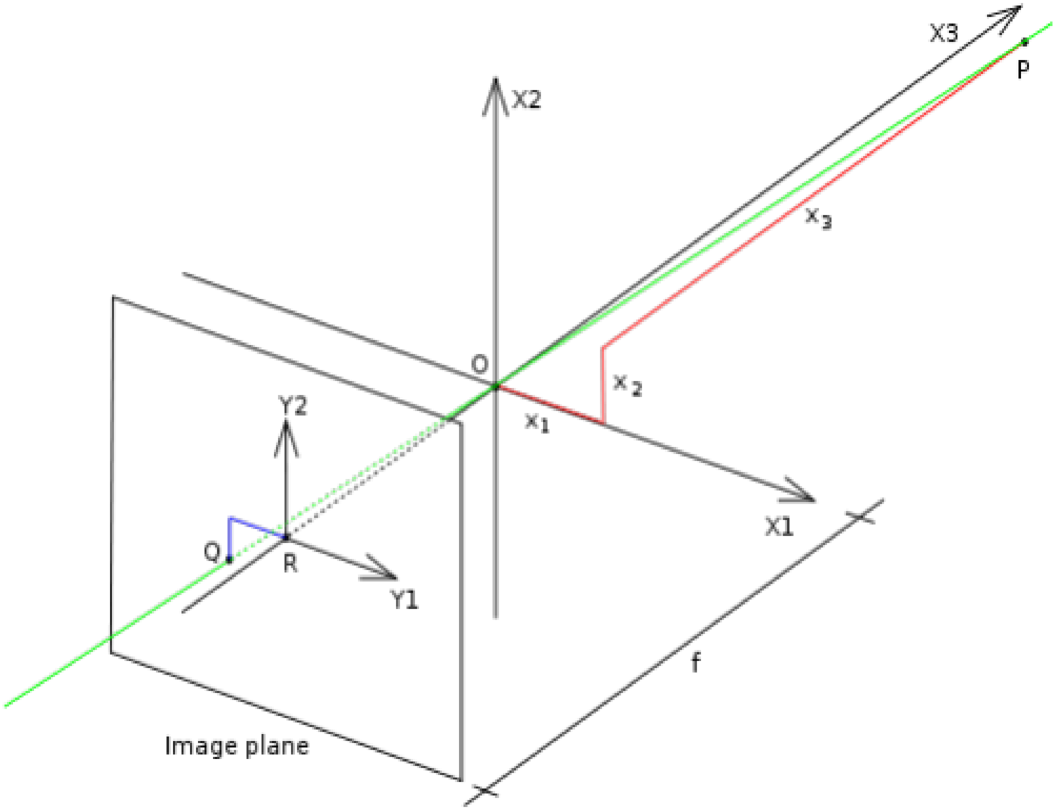


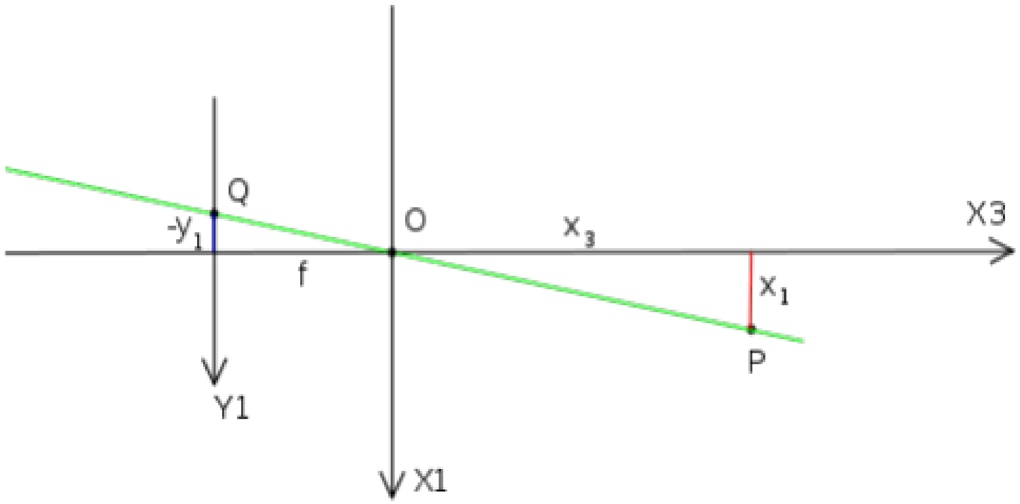




Some Constituents II

- Camera Model (pinhole)





Row Vs. Column Format

Remember this?

$$\mathbf{r}_0 = [x_0, y_0, z_0]^T$$

$$\mathbf{r}_d = [x_d, y_d, z_d]^T, \ ||\mathbf{r}_d|| = 1$$

$$\mathbf{r}_t = \mathbf{r}_0 + t \cdot \mathbf{r}_d$$

One degree-of-freedom

Row Vs. Column Format

$$\mathbf{v} = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \neq \begin{bmatrix} v_1 & v_2 & v_3 \end{bmatrix} \quad \left(= \begin{bmatrix} v_1 & v_2 & v_3 \end{bmatrix}^T \right)$$

column format

$$\mathbf{Mv} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

row format

$$\mathbf{v}^T\mathbf{M}^T = \begin{bmatrix} u & v & w \end{bmatrix} \begin{bmatrix} a & d & g \\ b & e & h \\ c & f & i \end{bmatrix}$$

transposed

$$\mathbf{Mv} = (\mathbf{v}^T\mathbf{M}^T)^T$$

Homogeneous Coordinates

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cdot & \cdot & \cdot & t_x \\ \cdot & \mathbf{R} & \cdot & t_y \\ \cdot & \cdot & \cdot & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Allow common operations to be represented as matrices

- Translation, rotation, projection

For positions and vectors, in 3D:

- $(x,y,z,w)^T \Rightarrow (x/w, y/w, z/w)^T$ for $w \neq 0$
- $w = 1.0$: position
- $w = 0.0$: vector

ROYAL INSTITUTE OF TECHNOLOGY

Lighting and Shading

- In this lecture, you will apply knowledge about:
  - Some applied math, especially vector algebra
- What is shading?
  - Determining the colour of a pixel
  - Usually determined by a *lighting model*
- Why is it good?
  - Provides depth to perception of images
  - Adds a sense of realism

Applications

Photorealistic

Applications

Non-photorealistic

ROYAL INSTITUTE OF TECHNOLOGY

Lighting Vs. Shading

- Lighting
  - Interaction between materials and light sources
- Shading
  - Deciding the colour of a pixel
  - Based usually on a lighting model
  - Other methods possible too though

How To Implement?

- Theory
  - General classifications
  - Lighting fundamentals
    - Lambertian illumination
  - Some shading models
    - Flat, Gouraud, Phong
  - Extensions
- Practice
  - Maths programming (vector operations, normals, plane, angles, intersections)

Some Classifications

- View Dependent
  - Determine an image by solving the illumination that arrives through the view-port only
- View Independent
  - Determine the lighting distribution in an entire scene regardless of viewing position. Views are taken after lighting simulation by sampling the full solution to determine the view through the viewport

ROYAL INSTITUTE OF TECHNOLOGY

Some Classifications

- Local Illumination
  - Consider lighting effects only directly from the light sources and ignore effects of other objects in the scene (e.g. reflection off other objects)
- Global Illumination
  - Account for all modes of light transport

Why Go Local?

- Usually easy to control and express
  - Director's chair: important when you want a scene to look a certain way
- Fast
  - Easier to obtain real-time performance (or just tractable calculations)
- Do not require knowledge of the entire scene

But …

- Not as accurate or compelling as global models

How Can It Be Modelled?

- Use a *lighting model* as inspiration
- But real light extremely complicated to simulate
  - Light bounces around the environment
  - Heavy processing required even for coarse approximations
  - Simplifications allow real-time performance
- Lighting models:
  - Lambertian – we will consider this first
  - Phong – not to be confused with *Phong shading*
  - Blinn-Phong and others...

Simplifications

- Simplification #1: use *isotropic point* light sources
- Isotropic means that the light source **radiates energy equally** in all directions
  - Simplifies our light source energy equations that we'll look at
  - When we mention light, we are really talking about **energy**
- Simplification #2: simulate only specific surface types
  - Makes it easier to specify materials and calculate reflections
  - But visually limited

Radiant Intensity

- Light is defined by its *Radiant Intensity*, **I**
  - Radiant Intensity is measured in *Watts/sr*
  - *sr* is the solid angle (in steradians)
  - $I = \phi / 4\pi r^2$
  - ϕ is the energy *leaving* the surface per unit time
  - Known as *power* or *flux* and measured in *Watts*
  - But: it's a point light source, so it radiates light equally in all directions
  - So $r^2 = 1$ (unit sphere)

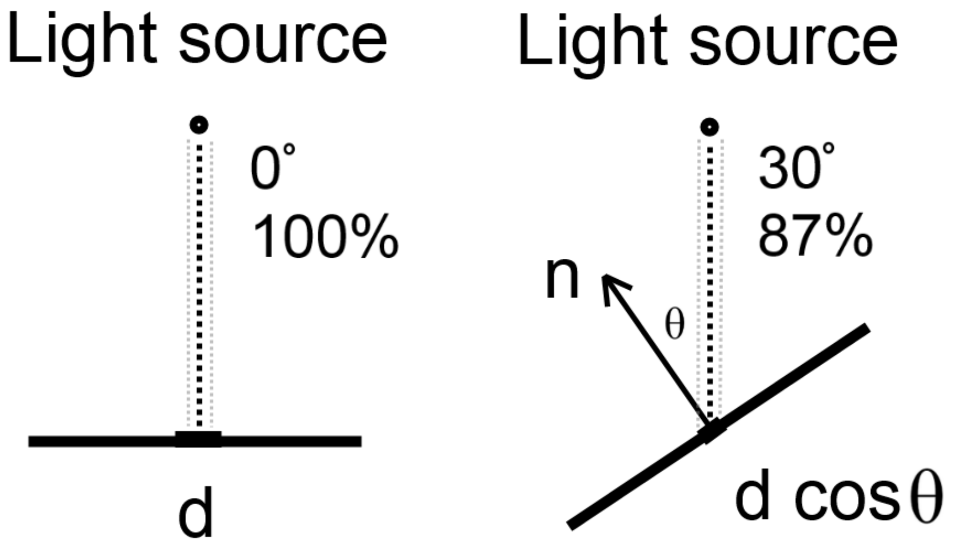
  $\Rightarrow \mathbf{I} = \phi / 4\pi$
- Now know energy leaving light source in any direction

Inverse Square Law

- But we want to know the energy *arriving* at a surface
- This *irradiance,* E, may now be determined:
  - Irradiance is the flux per unit area at a point x, a distance r from the point light source
  - We know the source radiates *I* Watts in all directions
  - So the power is radiated through a sphere centred at the lightsource
  - At a distance r from the source, the surface area of this sphere is $4\pi r^2$ => the power per unit area at x is: $\mathbf{E = \phi / 4\pi r^2}$
  - This assumes the surface at x is perpendicular to the direction to the light source
  - To handle all angles, we must apply the **cosine rule**

The Cosine Law

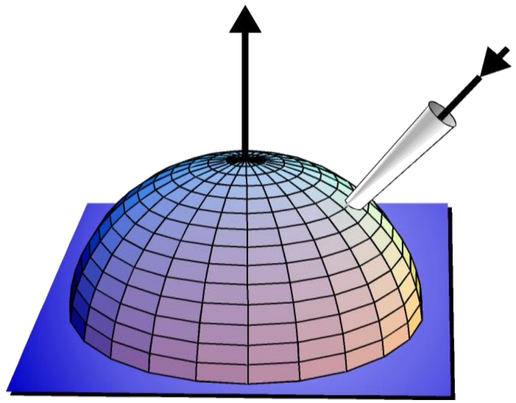
- A surface orientated perpendicular to a light source will receive more energy than a surface orientated at an angle to the light source
  - More energy = brighter appearance
- The irradiance E is proportional to 1/area
- As the area increases, the irradiance decreases
  - As θ increases, the irradiance (thus surface brightness) decreases:



Lambertian Illumination Model

- Cosine rule is used to implement Lambertian surfaces
  - Also known as *diffuse* surfaces
- Diffuse surfaces reflect light equally in all directions
- The surface is characterised by a reflectance parameter ρ_d

$$\forall\ \rho_d(x) = \phi_i / \phi_r$$



ϕ_i is the incident power

ϕ_r is the reflected power

- So the *reflectance* is the ratio of

the total incident power to the total reflected power

Lambertian Illumination Model

- To shade a diffuse surface, we need to know
  - The normal to the surface at the point to be shaded
  - The diffuse reflectance of the surface
  - The positions and powers of the light sources in the scene
- Assuming contribution is from a single isotropic light source:

$$L_{r,d}(x, .) = (\rho_d / \pi) \cos\theta \, (\phi_s / 4\pi d^2)$$

  - (ρ_d / π) accounts for the reflectance attribute of the surface
  - $\cos\theta \, (\phi_s / 4\pi d^2)$ accounts for the orientation of the surface with respect to the light source

Lambertian Illumination Model

- This is *local illumination*
  - Only concerned with energy hitting the surface directly from light sources
  - Not concerned with light bouncing off other surfaces and hitting the surface

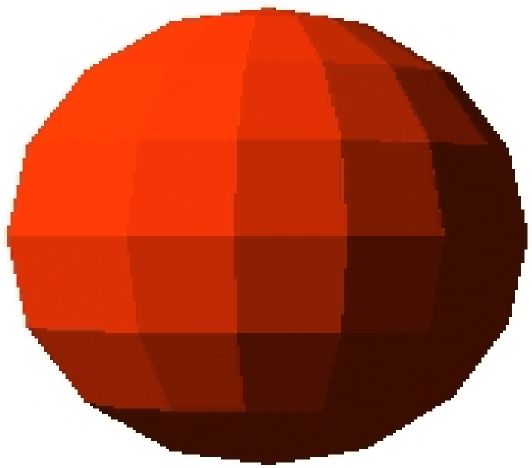
  - =>Models derived from it are also local

Basic Shading Models

- Flat, gouraud and phong shading
- Flat shading
  - Per polygon shading
- Gouraud shading
  - Interpolate (bilinearly) colour values to get tween pixels
  - Per vertex shading
- Phong shading
  - Interpolate normals
  - Per pixel shading

Flat Shading

- Constant shading
- Very fast
- Very simple
- Does not look very smooth
- Compute the colour of a polygon
- Use this as the colour for the whole polygon



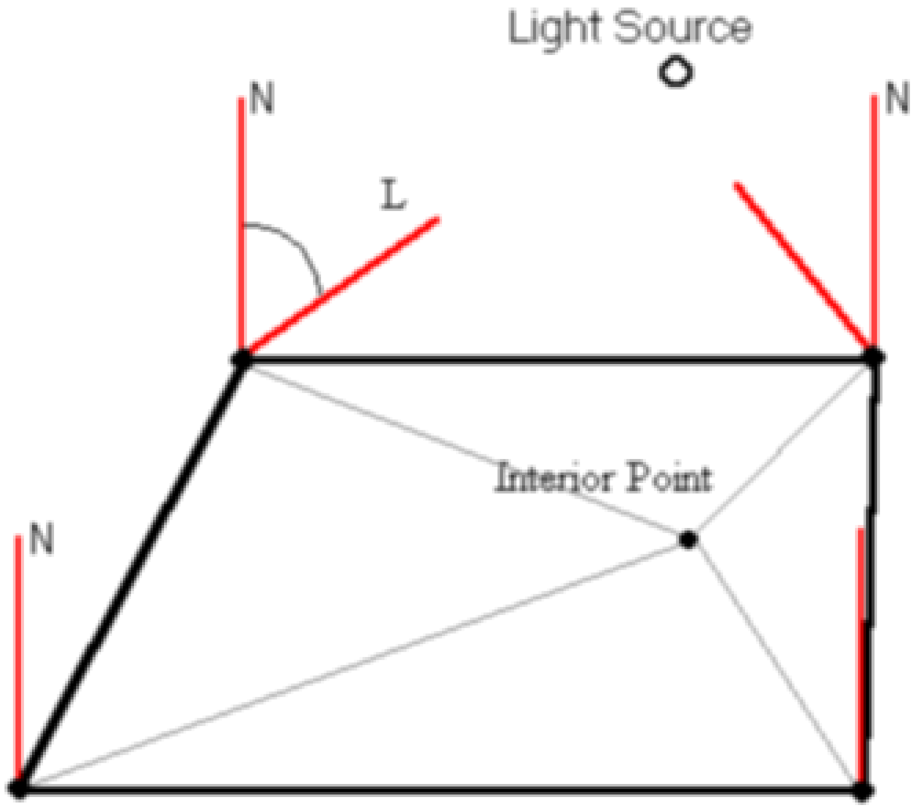
Flat

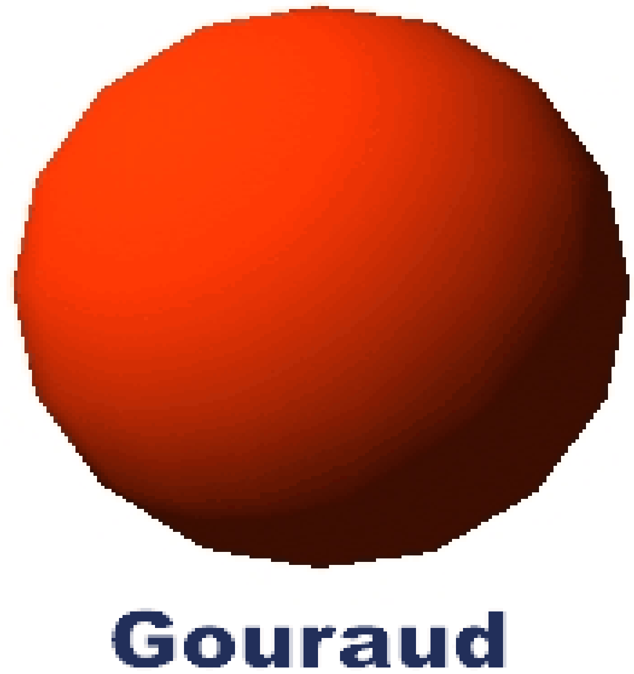
ROYAL INSTITUTE OF TECHNOLOGY

Gouraud Shading

- Calculates the light intensity at each vertex in a polygon
- For each interior point in the polygon, we *interpolate* the light intensity determined at the vertices
- Given a starting value, and an end value, *interpolation* can be used to approximate intermediate values
  - Similar idea to the way in which colours are interpolated across the surface of a polygon
- We only need to do lighting calculations at the vertices
  - Fast !
- But lighting is only correct at the vertices
  - Unrealistic

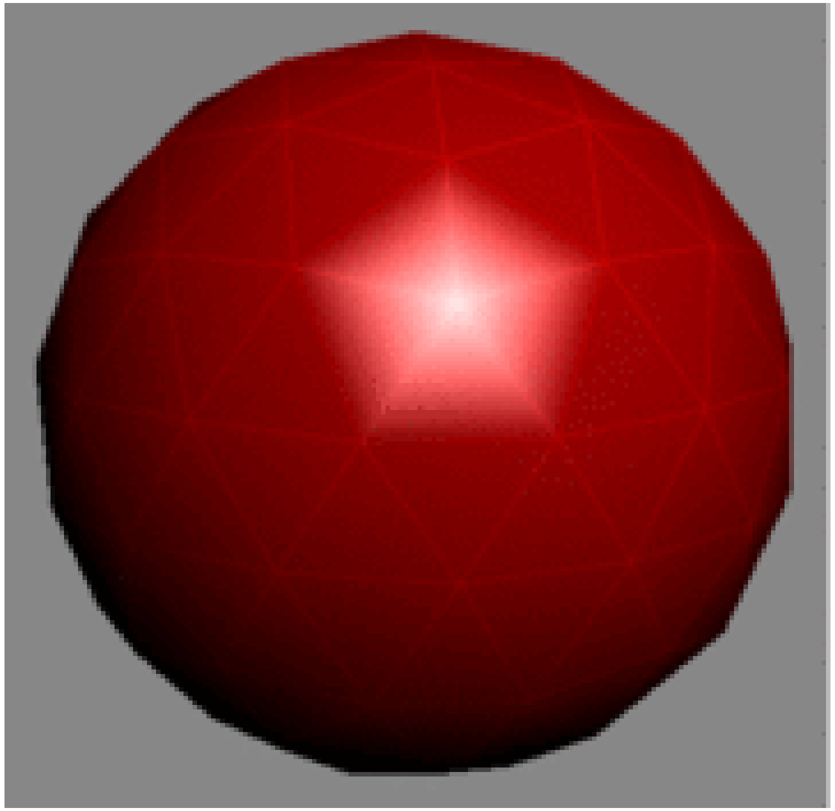
Gouraud Shading

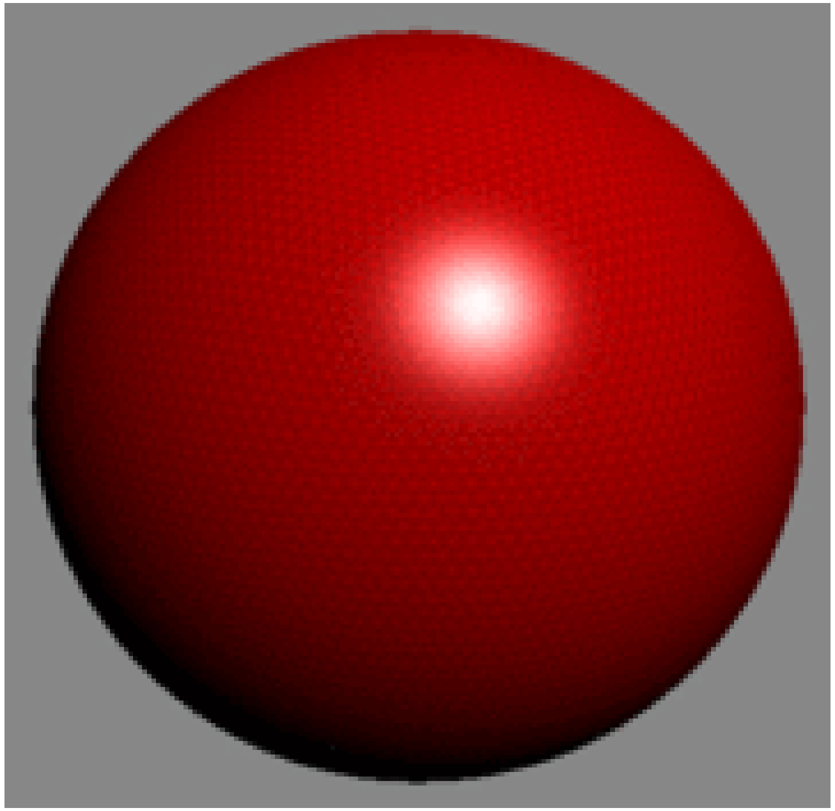




Limitations

- Gouraud only calculates the actual lighting at the vertices of the polygon

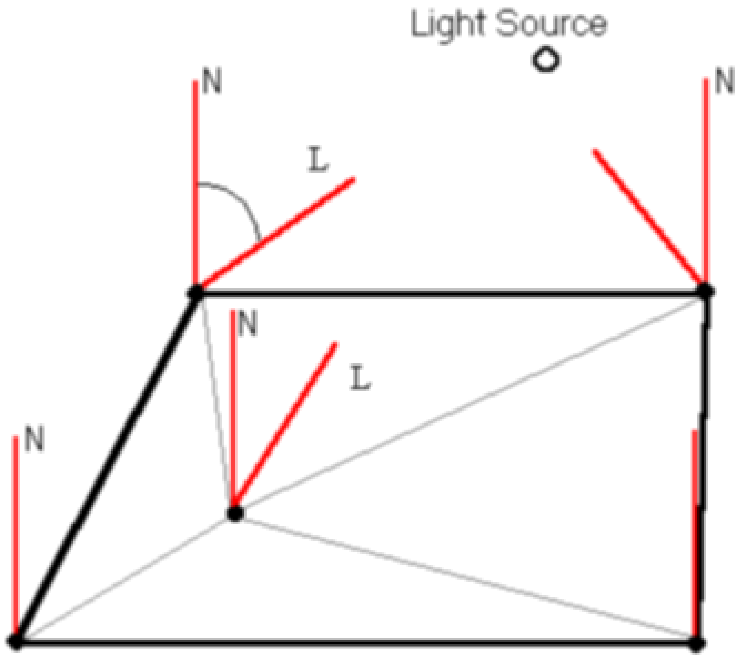


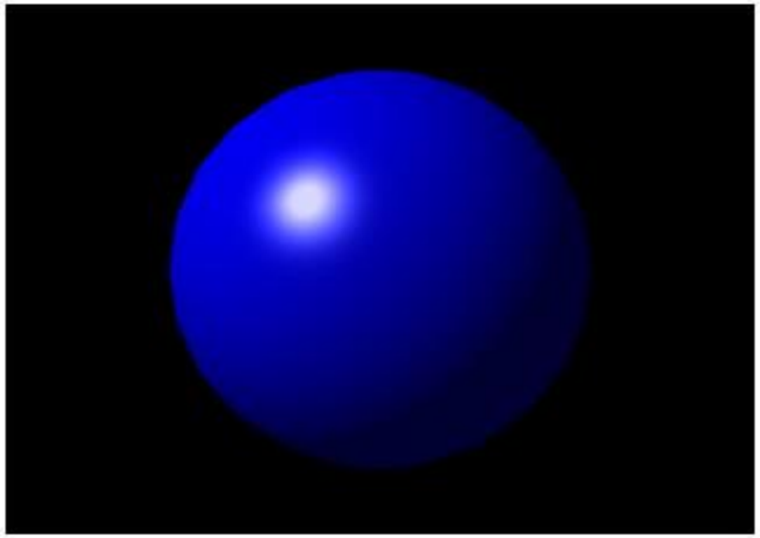


Phong Shading

- To improve on Gouraud shading, interpolate normals across a surface
  - Lighting model then applied to each interior point in a polygon
- Must take care to ensure that all interpolated normals are of unit length
- This is known as *Phong Shading*
- Phong shading produces more accurate results than Gouraud Shading
- But slower !

Phong Shading





PHONG SHADING

- Phong shading can reproduce highlights in the center of a polygon that Gouraud Shading may miss

Phong Illumination Model

- Lambertian Illumination model: only diffuse surfaces
  - Surfaces reflect light in all directions equally
- What about modelling shiny surfaces too?
  - Reflected radiance depends heavily on the outgoing direction
- Phong Illumination model consists of:
  - Lambertian Model for diffuse surfaces
  - A function to handle specular reflection
  - Ambient term to approximate all other light

Phong Illumination Model

<u>NOT the same as Phong Shading</u>

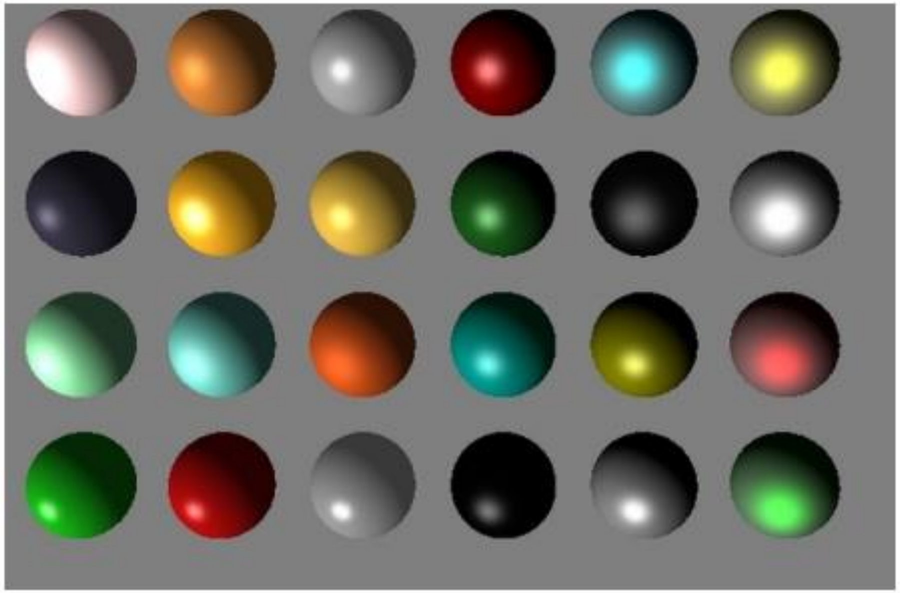
Phong Illumination Model

- Allows us to model many different types of surfaces
- Easy to <u>control</u>
- Not a very realistic model
  - But produces good results
- Each object has material data associated with it:

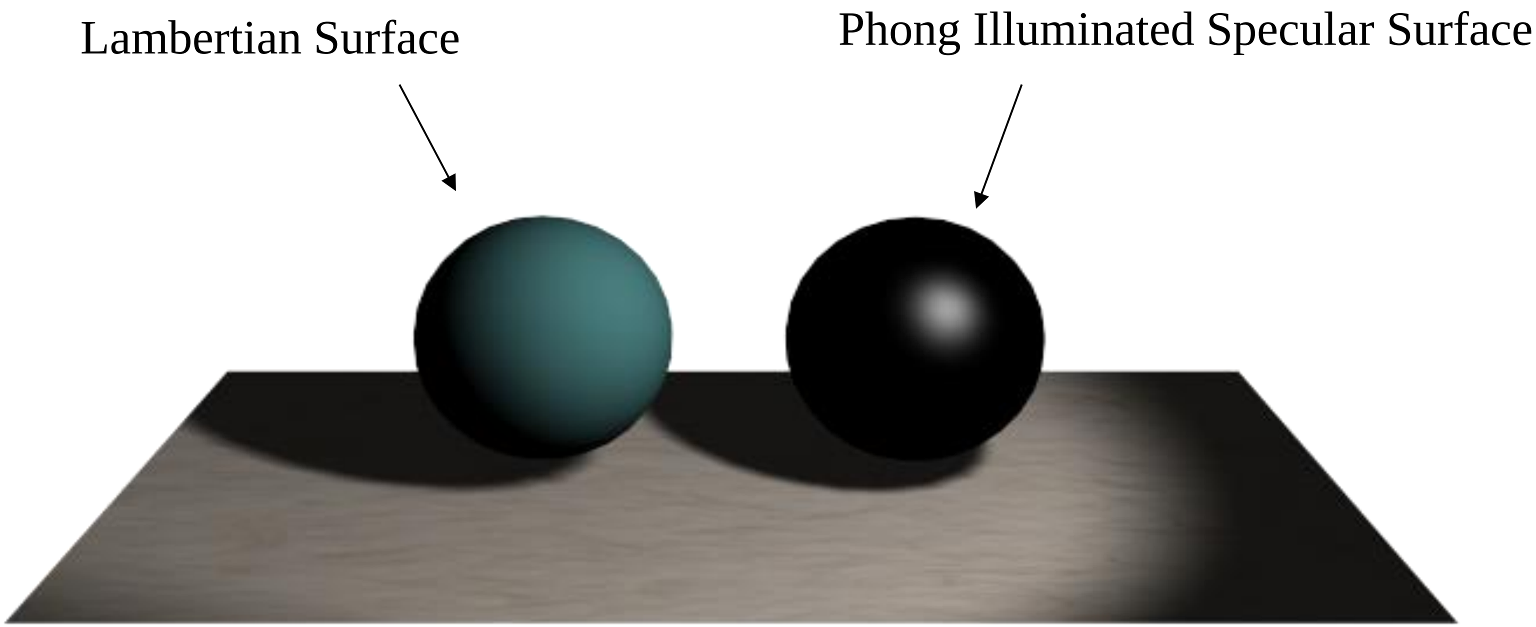
ρ_a	ambient reflectance
ρ_d	diffuse reflectance
ρ_s	specular reflectance
n	phong exponent (shininess parameter)

Materials

- Parameters:
- Interaction with light
- Reflective properties
- Components
  - $m_{ambient}$, $m_{diffuse}$, $m_{specular}$
- Proportion of each colour reflected



Lambertian Vs Phong



A little bit of OpenGL (1.2 ← old)

- Light sources
- LIGHT0 to LIGHT7
- Each light must be enabled …

```
glEnable(GL_LIGHT1);
```

- Can specify light parameters using

```
glLightf{iv}(GL_LIGHT0, param, value);
```

- Some parameters

```
GL_AMBIENT
GL_DIFFUSE
GL_SPECULAR
GL_POSITION
```

Shading in OpenGL 1.2

- To enable lighting use:

```
glEnable(GL_LIGHTING);
```

OpenGL does not support true Phong shading; it interpolates the intensities across each polygon

Gouraud shading

```
glShadeModel(GL_SMOOTH);
```

Material Properties

- We can assign different properties to each side of a polygon
- To assign material properties:

`glMaterial{if}v(face, param, value);`

face:

- GL_FRONT
- GL_BACK
- GL_FRONT_AND_BACK

param:

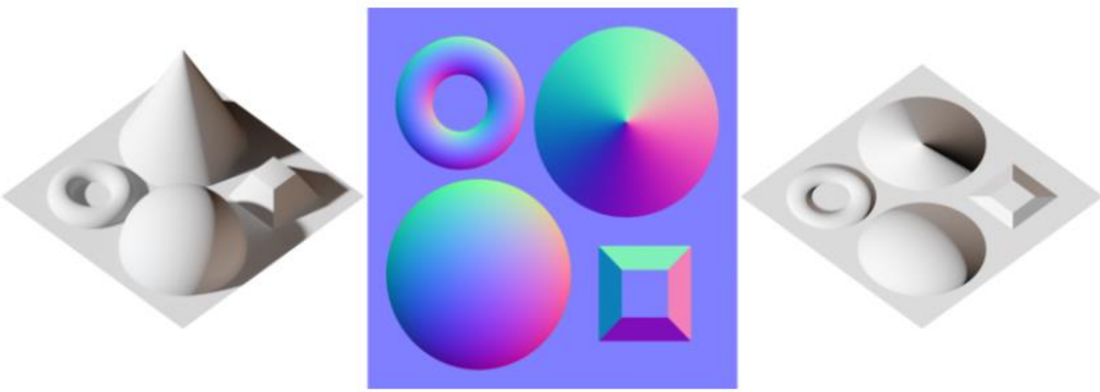
- GL_AMBIENT
- GL_DIFFUSE
- GL_AMBIENT_AND_DIFFUSE
- GL_SPECULAR
- GL_EMISSION

→ RGB Values

- GL_SHININESS ← Phong Exponent

Bump Mapping

- Lots of cool effects possible
- Bump mapping: modify surface normals for lighting calcs (not actual geometry)
- Query a heightmap
- See also: normal mapping



Shaders

- Modern way of implementing rendering techniques
- Various types:
  - Pixel
  - Vertex
  - Geometry
  - Tessellation
- Shader languages
  - HLSL, GLSL, CG
  - http://forum.unity3d.com/threads/announced-advanced-shader-pack.155683/

color outputs to pixel shader.

```
void main( in a2v IN, out v2p OUT )
{
```

input parameters include view project matrix ModelViewProj, view inverse transpose matrix ModelViewIT, and light vector LightVec.

```
    OUT.Position = mul(IN.Position, ModelViewProj);
```

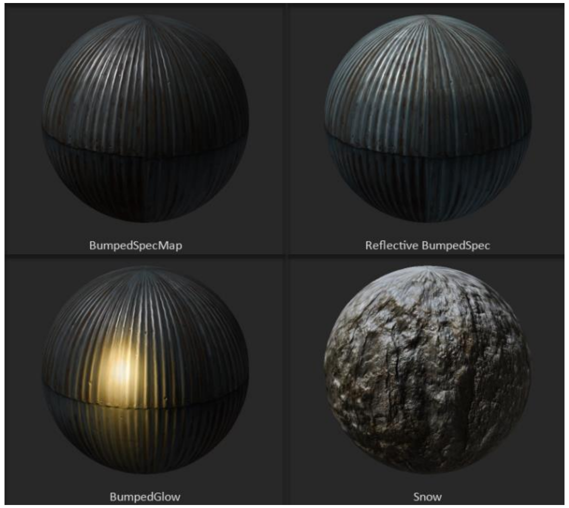
multiply position with view project matrix

```
    float4 normal = mul(IN.Normal, ModelViewIT);
    normal.w = 0.0;
    normal = normalize(normal);
    float4 light = normalize(LightVec);
    float4 eye = float4(1.0, 1.0, 1.0, 0.0);
    float4 vhalf = normalize(light + eye);
```

transform normal from model-space to view-space, store normalized light vector, and calculate half angle vector. float4(1.0, 1.0, 1.0, 0.0) is a vector constructor to initialize vector float4 eye.

.xyzz, a swizzle operator, sets the last component w as the z value.

```
    float diffuse = dot(normal, light);
    float specular = dot(normal, vhalf);
    specular = pow(specular, 32);
```



Next lecture

- Next week (25th April)
- 10:00 – 12:00 B2

- Lab support session
- 15:00-17:00 (starting now)
- 4V2Röd