Materials and lighting

Computer Graphics (DT3025)

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November 7, 2016

Today

- Light, irradiance, etc.
- What is a BSDF, and how to use it.

Reading material

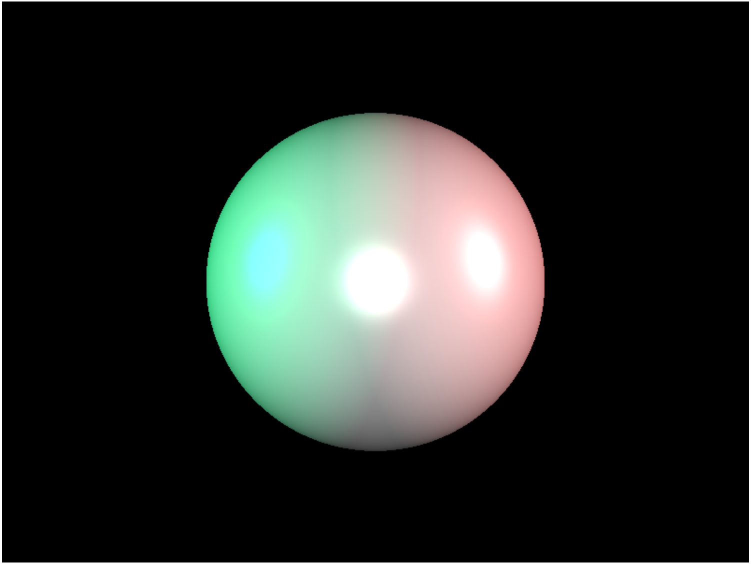
Hughes et al.:

- 6.2.2–6.3, 6.5
- 14.9
- 27.1–8

Akenine-Möller et al.:

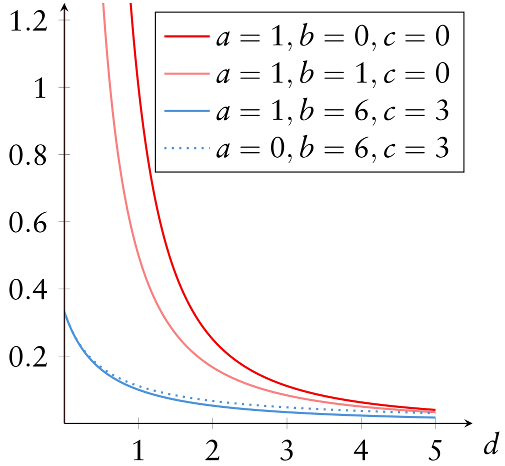
- *Chapter 7*

Lights and colours



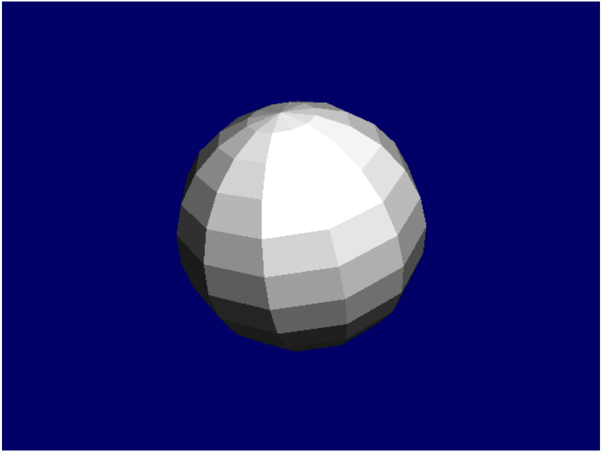
Intensity fall-off

intensity $(ar^2 + br + c)^{-1}$



Flat shading

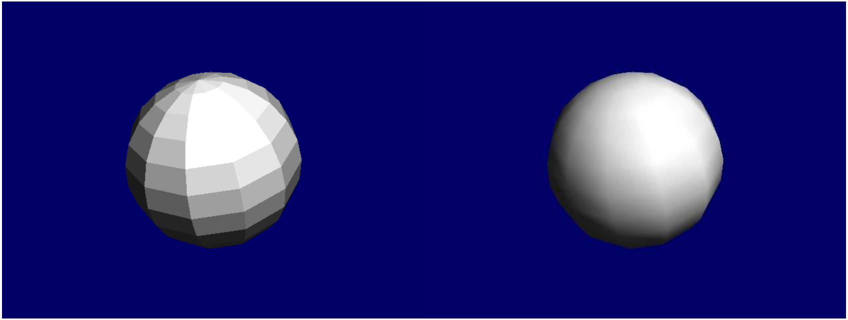
- Illumination is calculated *once per patch*.



Mathias Broxvall

Gouraud shading

- Compute colour *per pixel* instead of *per face*.
- Flat-shaded vs Gouraud-shaded “sphere”:



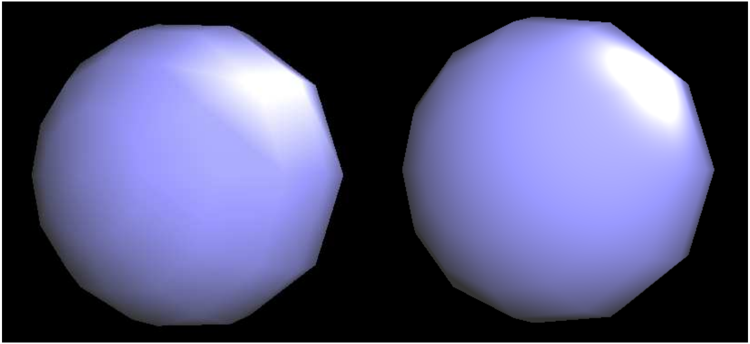
Mathias Broxvall

- What’s wrong with this?

Mach banding

Phong shading

- Interpolate *normals* for every pixel instead of *colour*.
- Compute lighting using per-pixel normals.
- Gouraud-shaded vs Phong-shaded “sphere”:

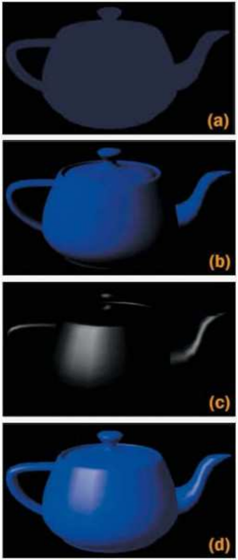


Now let's model light and materials

- Last few slides: "shading" = interpolation.
- From now on, let's talk about *light and reflection models* instead (and the *shaders* used to compute them).

Traditional Phong lighting

- Reflected light (d) = sum of three components:
  - (a) “ambient light”,
  - (b) ideal diffuse (= Lambertian) reflection,
  - (c) glossy “specular” reflection.



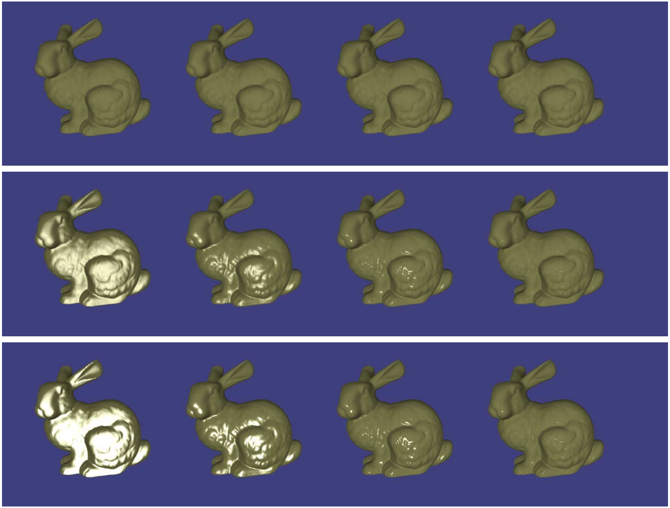
Hughes et al. 2013

Phong: example parameters

$k = 0.0$

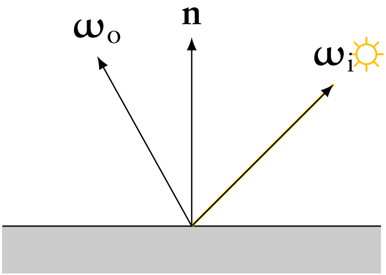
$k = 0.5$

$k = 1.0$



$f = 1$ $\quad f = 10$ $\quad f = 100$ $\quad f = 1000$

BRDF: bidirectional reflectance distribution function



- "How much light reflects from any input direction to any output direction?"

BRDF visualised

- For a fixed incoming direction, view dependence is a 2D (spherical) function.

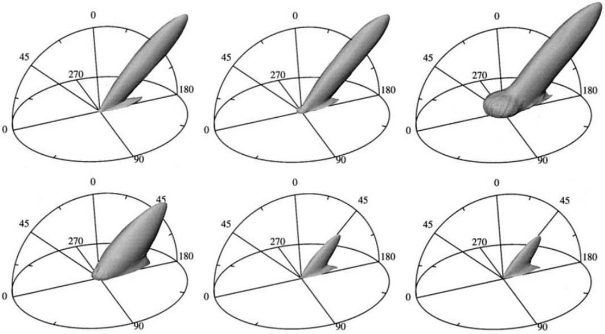


Fig. 16. Resampled scattering diagrams of the BRDF measurements of two paints: a blue enamel (top row) and a red automotive lacquer (bottom row). The RGB color measurements are shown from left to right.

Marschner et al. 2000

BRDF measurement

- Gonioreflectometer:

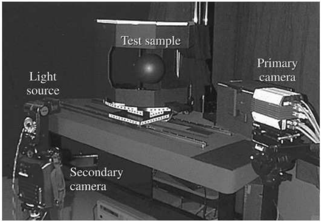


Fig. 1. Measurement setup.

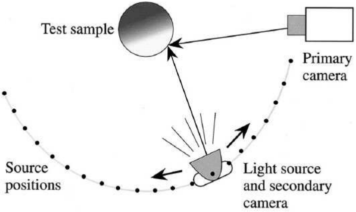
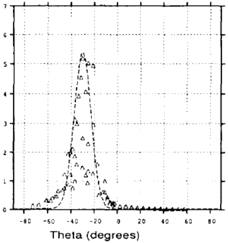


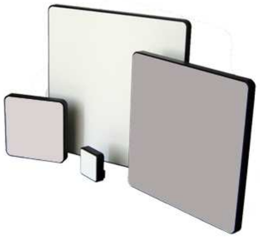
Fig. 2. Schematic of the measurement setup.

Marschner et al. 2000



1. Collect table with (noisy) data.
2. Tabulate and/or fit model to the data.

Lambertian reflectors



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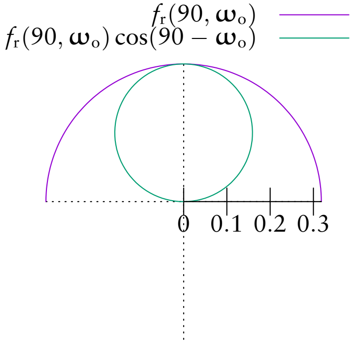
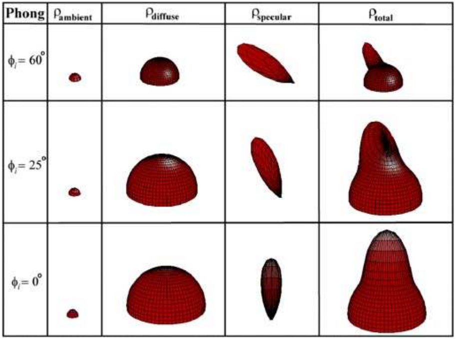


Blinn–Phong as a BRDF

- Normalised Blinn–Phong BRDF that conserves energy:

$$f_r = \frac{k_L}{\pi} + \frac{8+f}{8\pi} k_g (\mathbf{n} \cdot \mathbf{h})^f$$

Lambertian
energy conservation
Blinn–Phong specular term



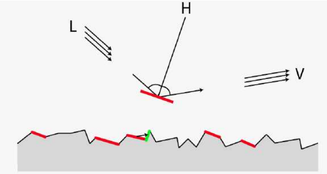
Pascal Vuylsteker

Fresnel reflection

- Specularity increases at grazing angles.

Prabhu B, via Wikipedia

Cook–Torrance specularity



Jaakko Lehtinen

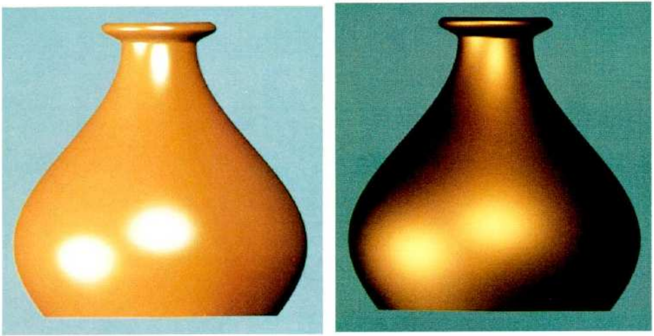
- Assumes surface consists of microscopic “grooves”, or microfacets.
- Microfacets are perfect mirrors.

  - D: amount of microfacets reflecting in a given direction
  - G: microfacet geometric factor (depending on *self-shadowing* and *masking*)
  - F: Fresnel coefficient
    - This is a function of the light angle and the *refractive indices* of the *two* materials.

$$C_{\text{spec}} \propto F(\boldsymbol{\omega}_{\text{i}}, n_1, n_2) \frac{D}{\mathbf{n} \cdot \boldsymbol{\omega}_{\text{i}}} \frac{G}{\mathbf{n} \cdot \boldsymbol{\omega}_{\text{o}}}$$

  - Result: Better specular highlight (e g, water, metal).

Cook–Torrance example



(a) (b)

Fig. 6. (a) A copper-colored plastic vase. (b) A copper vase.

Cook et al. 1981

Oren–Nayar

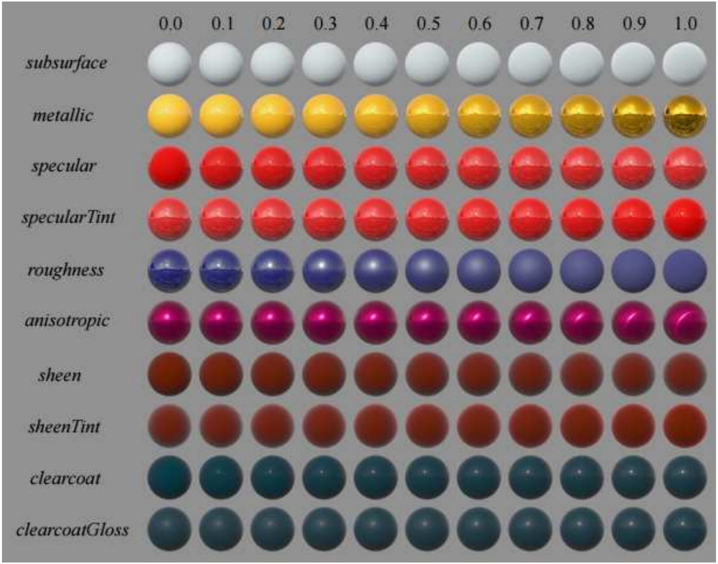
- Better diffuse reflection of rough surfaces.
- Model surface as as Lambertian microfacets.

Disney's principled shader

- Need a single model that can *plausibly* model a wide range of materials.
  - No "parameter explosion" for the artists.
- Principles:
  1. Intuitive rather than physical parameters.
  2. As few parameters as possible.
  3. Parameters should be zero to one over "plausible range".
  4. Allow parameters to go beyond plausible range.
  5. All combinations of parameters should be robust and plausible.
- Final model: 10 scalars for surface characteristics (plus colour).
- Match model with database of 100 measured BRDFs.

If you're interested, you can read more here and here.

"Principled shader" parameters



Burley 2012

Model, view, perspective matrices

- Before:
  - Compute “final” transformation matrix as product of sequence of primitive transformations.
  - Pass to vertex shader (as a uniform variable).
  - Vertex shader multiplies each vertex position with this matrix.
- What about normals and light–object vectors?
  - Separate *projection* matrix from the *modelview* matrix
  - For rasterization: multiply with both.
  - For light computations: multiply with only modelview.
  - What happens otherwise?

Model, view, and projection

- You have a triangle $(0, 0, 0; 0, 1, 0; 1, 0, 1)$ in object-local coordinates.

Model Bring your triangle into world coordinates: apply *model matrix*.

View Move your world around a camera (into camera coordinates): apply *view matrix*.

Projection Release shutter! Apply *projection matrix*.

Example shader code

Vertex shader

```
layout(location=0) in vec4 inPosition;
layout(location=1) in vec4 inNormal;
layout(location=2) in vec4 inDiffuse;
out vec4 normal;
out vec4 position;

uniform mat4 projectionMatrix;
uniform mat4 modelviewMatrix;

void main() {
  gl_Position = projectionMatrix * modelviewMatrix * inPosition;
  normal = modelviewMatrix * inNormal;
  position = modelviewMatrix * inPosition;
}
```

- (Spot a bad design choice with this code.)

Point to the most Lambertian surface around you.

Something that is designed to reflect equally in all directions, like ceiling paint.

Point to the surface with the largest "diffuse" *red* component.

Most likely this will be a *white* surface, with large red+green+blue components.

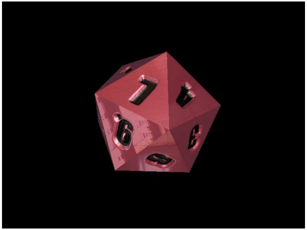
Point to the surface with the largest ambient component.

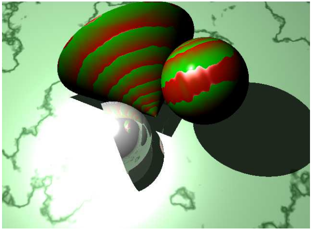
Trick question: the ambient term is just a hack in the Phong model.

Summary

- Shading (historical) vs shaders for reflectance modelling
- Reflectance models
    - Phong
    - Blinn–Phong
    - Cook–Torrance
    - Oren–Nayar
- BRDF: bidirectional reflectance distribution function, and its place in computing the colour of a pixel
- Transformations and lighting

Next lecture: textures and mapping techniques





- Tue Nov 8, 15.15–17.00
- T-211
- Hughes et al.:
  - 7.9–7.9.1,
  - 9.6,
  - 20.1–20.8.2.

References

- Brent Burley (2012). "Physically-Based Shading at Disney". In: *SIGGRAPH Course Notes*.
- R. Cook and K. Torrance (1981). "A reflectance model for computer graphics". In: *Computer Graphics* 15.3, pp. 301–316.
- John F. Hughes et al. (2013). *Computer graphics: principles and practice (3rd ed.)* Boston, MA, USA: Addison-Wesley Professional, p. 1264. ISBN: 0321399528.
- Stephen R. Marschner et al. (2000). "Image-based bidirectional reflectance distribution function measurement". In: *Applied Optics* 39.16.