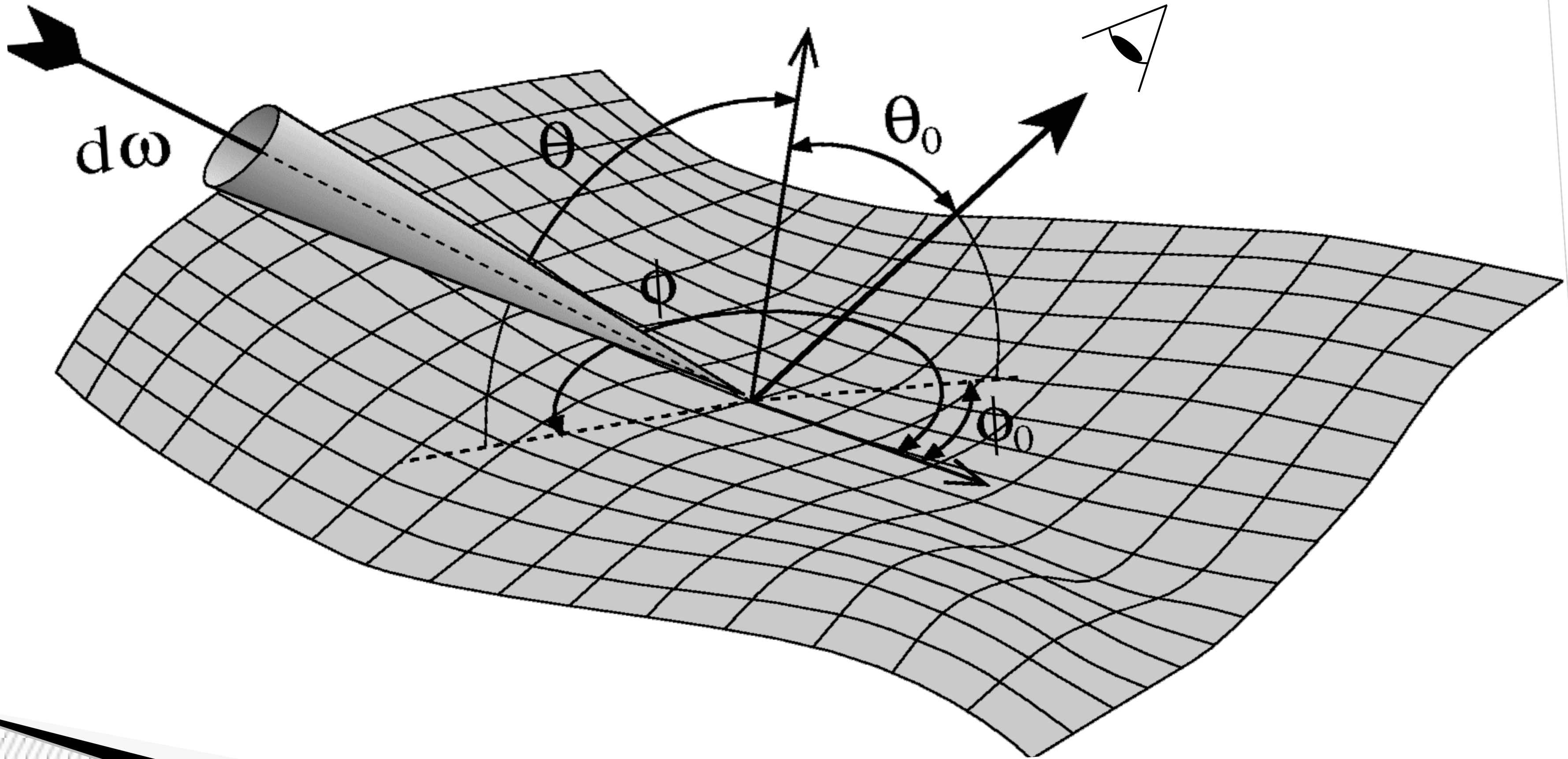
Material representation, Reflectance, BRDFs

Local illumination models

- A single point light source
- Linear combination for several light sources
  - I(a+b) = I(a)+I(b)
  - I(s . a) = s . I(a)
- No interactions between objects
  - No shadows, no reflections
- Computing color independently for each pixel

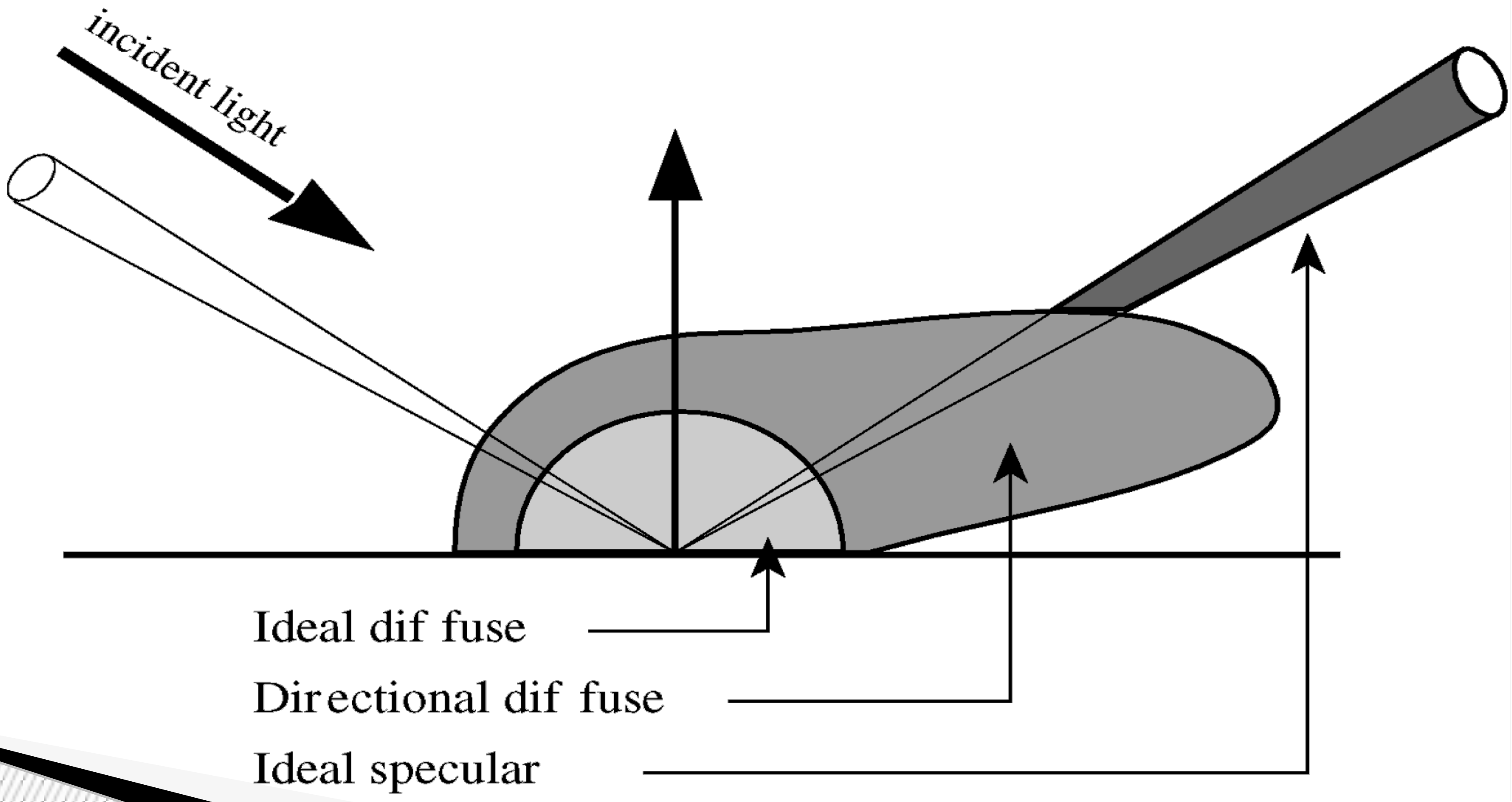
BRDF: Bi-directional Reflectance Distribution Function

- 4D Function: $f(\theta,\phi,\theta_0, \phi_0)$, tells how the light is reaching a point is reflected



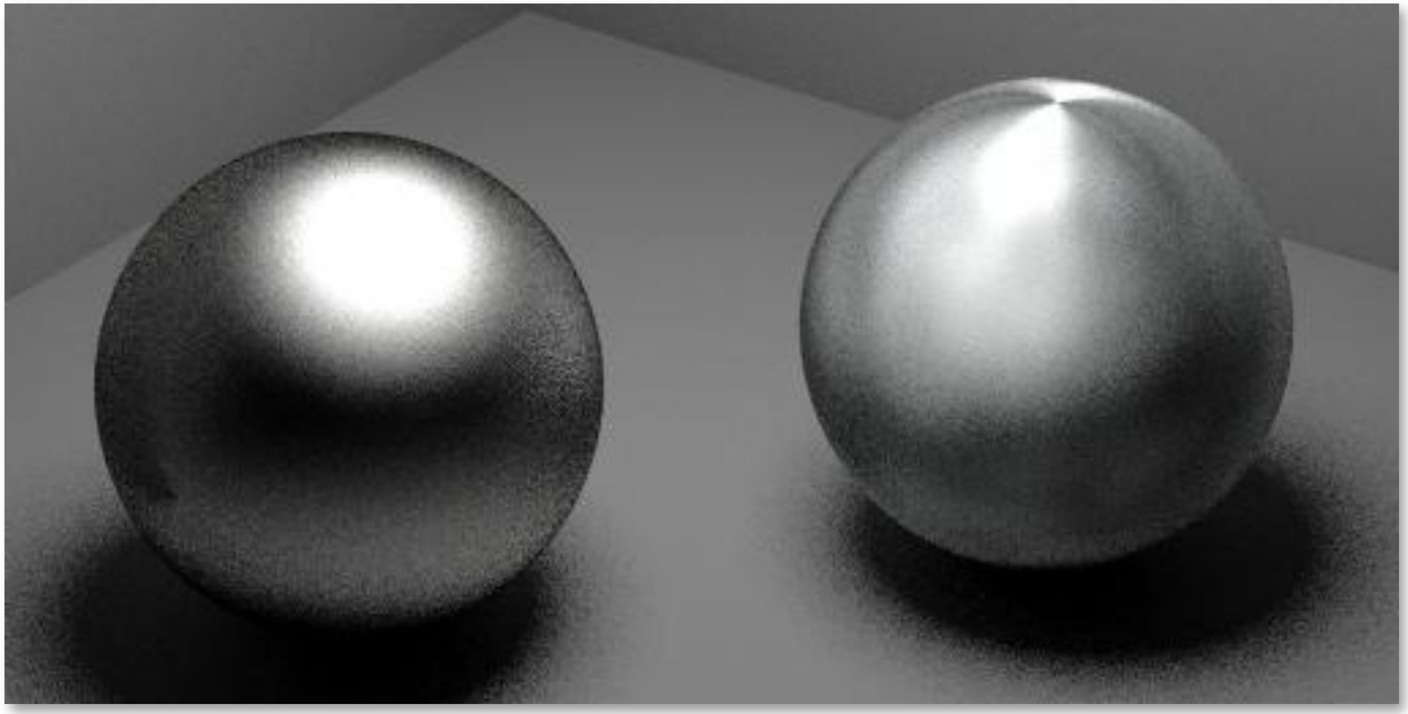
BRDF

- Ratio between incoming light and outgoing light
- Complete description of the behaviour of the material at each point, for every incoming and outgoing direction



BRDF – Isotropic vs. anisotropic?

- Isotropic
  - Rotationally invariant (3D)
  - True for many materials
  - One dimension less
- Anisotropic
  - Depends on the angle of rotation around the surface normal

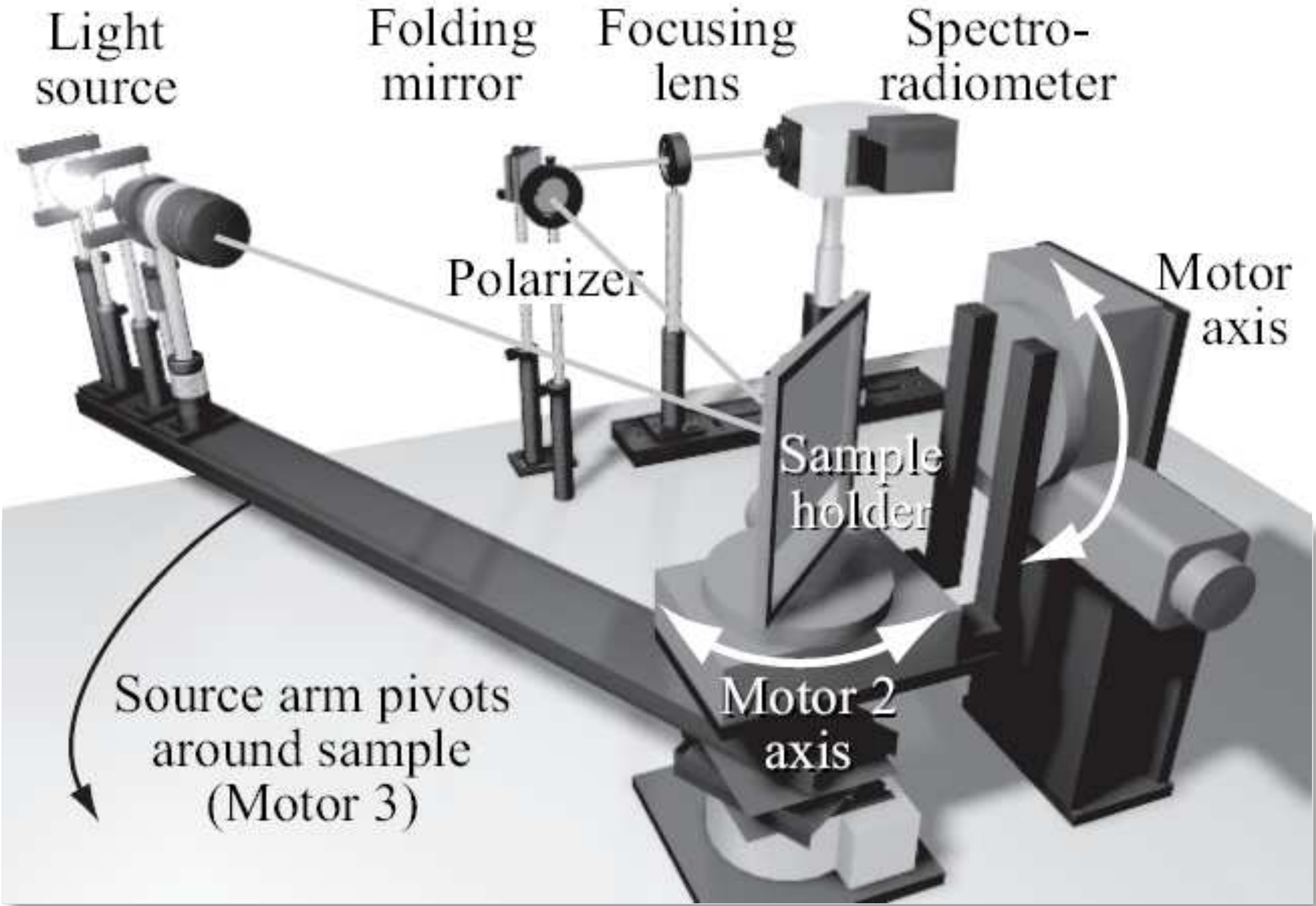


BRDF – Representation

- Constraints:
  - Storage space
  - Accurate representation of the properties of a material
  - Fast and easy sampling
- 2 solutions:
  - Explicit storage of measured data
  - Approximation through an analytical model

BRDF – Acquisition

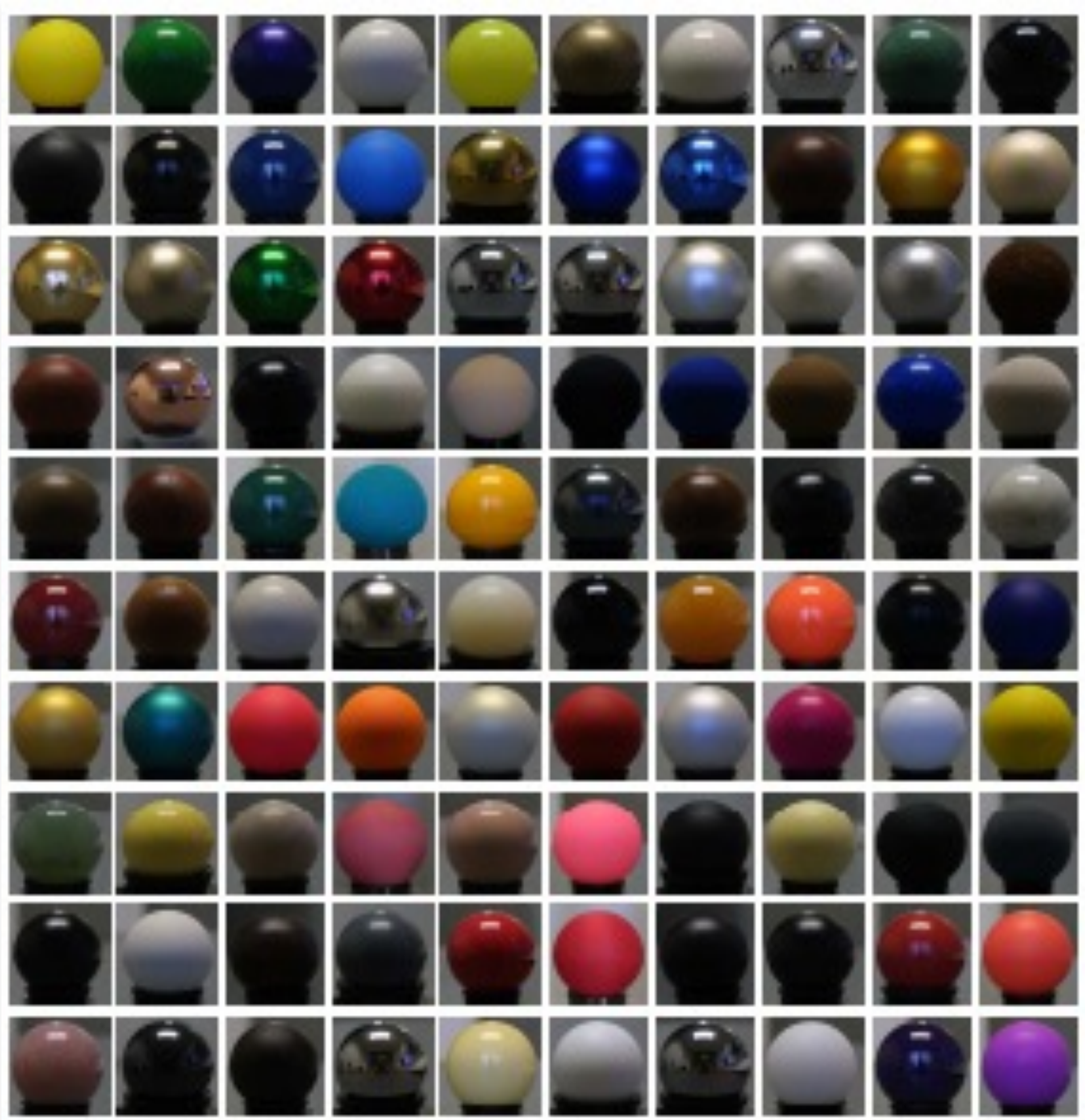
- Acquisition system: gonioreflectometer



http://www.graphics.cornell.edu/~westin/

BRDF – Database

- MERL dataset
  - 100 measured materials

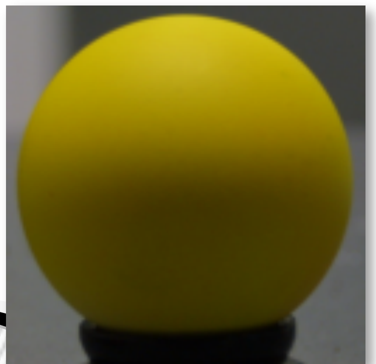


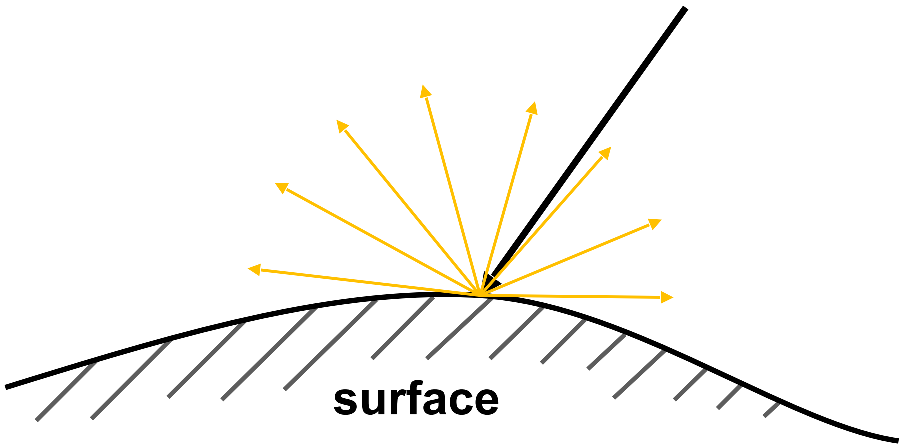
BRDF- Analytical models

- Empirical
  - Lambert, Phong, Blinn, Ward, Lafortune
  - Can be combined for increased realism
  - Easy to use
- Physically based models
  - Torrance-Sparrow, Cook-Torrance, Kajiya…
  - Need information on the material (roughness…)

Ideal diffuse reflection

- Diffuse reflexion
  - Object reflecting light uniformly in all directions
- Lambertian surfaces (mate: chalk, paper)
  - Intensity at one point: only depends on the angle between incoming light and surface normal
- Uniform BRDF





Diffuse reflection

increasing ρ_d

$$I = \rho_d \cos\theta$$

Ambiant light

- Trick for better visual realism
- No relation with physical realism
- Light independent from position:

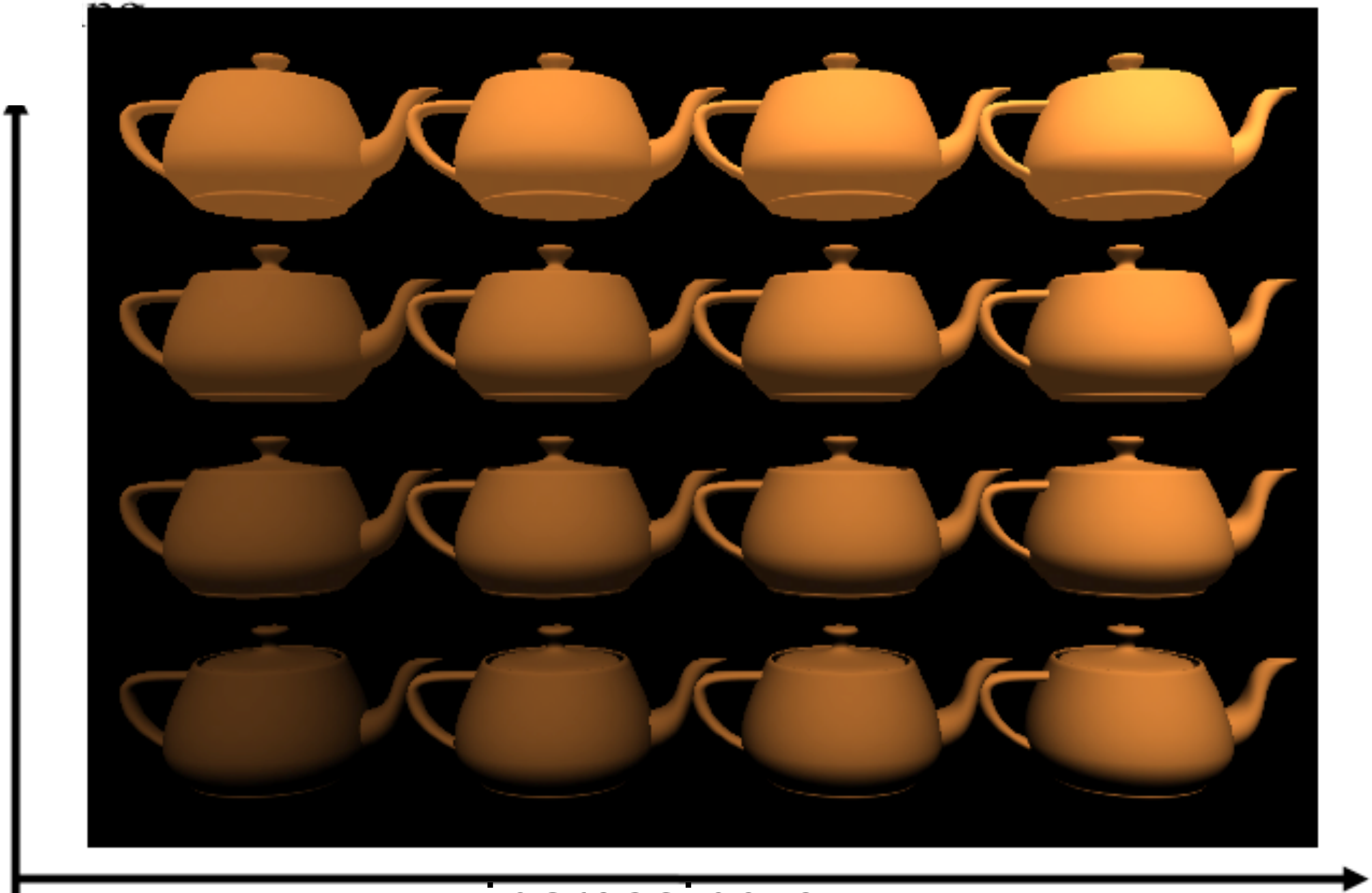
$$I = \rho_a \, I_a$$

- Very simple model:
  - no visible 3D effect
  - useful to hide some defects

Ambiant light

increasing ρ_a

Diffuse + ambiant



Oren–Nayar model [1993]

- rough diffuse materials

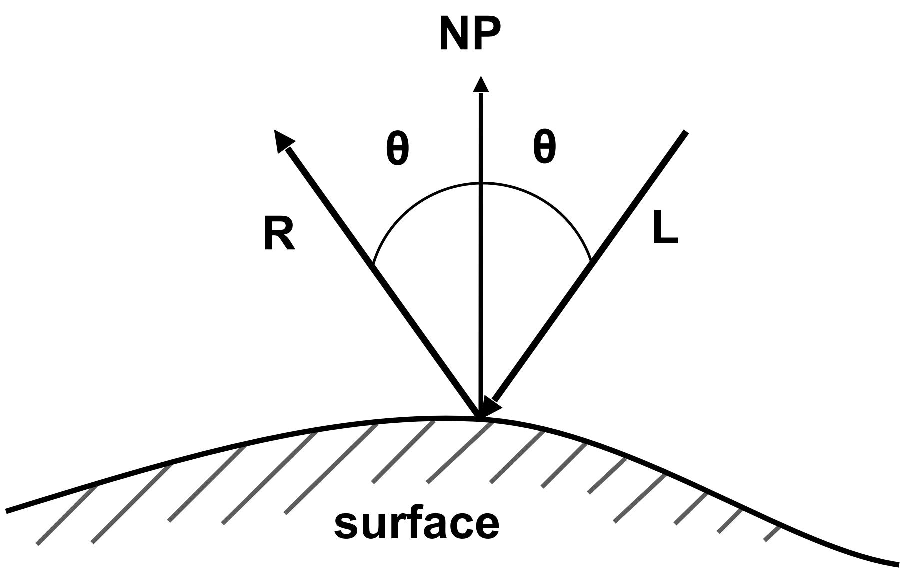
Photograph

Diffuse model

Oren-Nayar

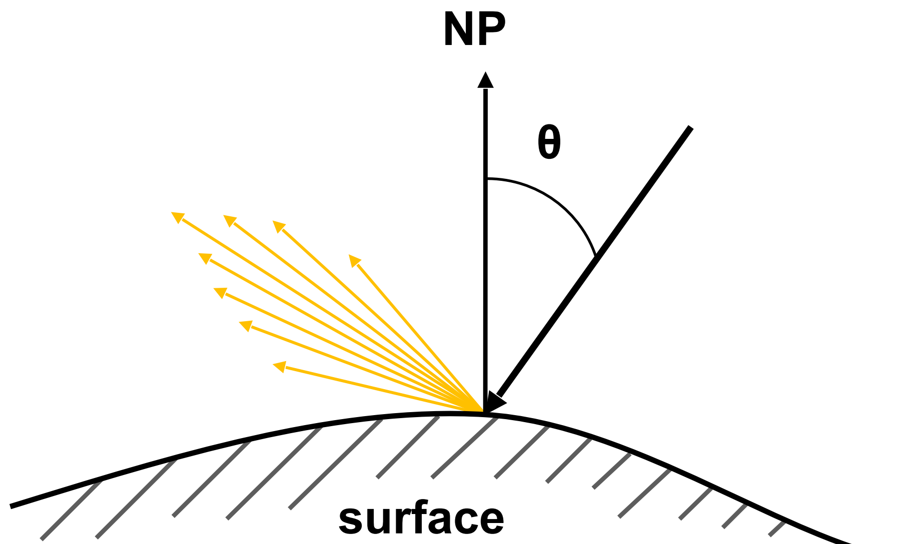
Ideal specular reflection

- Specular reflection
  - Smooth, shiny surfaces (mirrors, metals)
- Snell / Descartes law
  - Light reaching a point reflected in the direction having the same angle with the normal
- BRDF: Dirac distribution



Non-ideal specular reflection

- Problem: ideal specular reflection limited
  - Useful for indirect lighting
  - Less so for direct lighting with point light sources
  - Assumes perfectly smooth surfaces
- Phong model
- Fresnel coefficients



Phong model [1975]

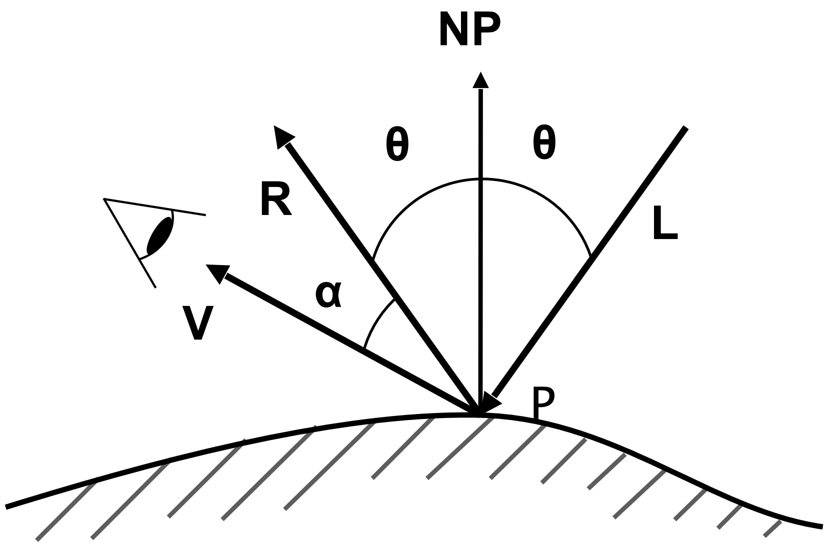
- Intensity varying with angle α between viewing direction V and reflected direction R

  (R symmetric of L w.r.t. the normal)

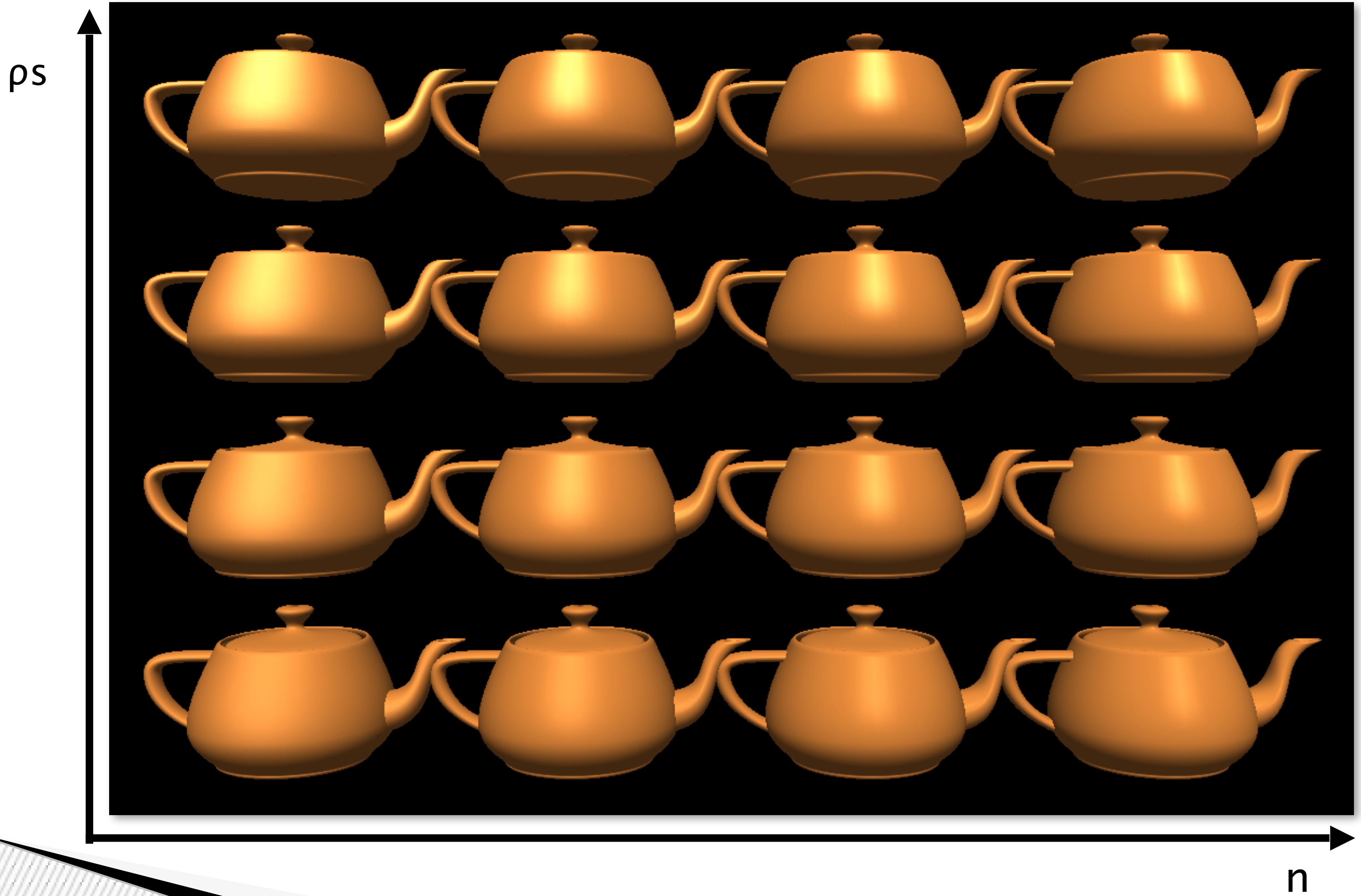
$$I(P) = \rho_s \quad L \quad \cos^s \alpha$$

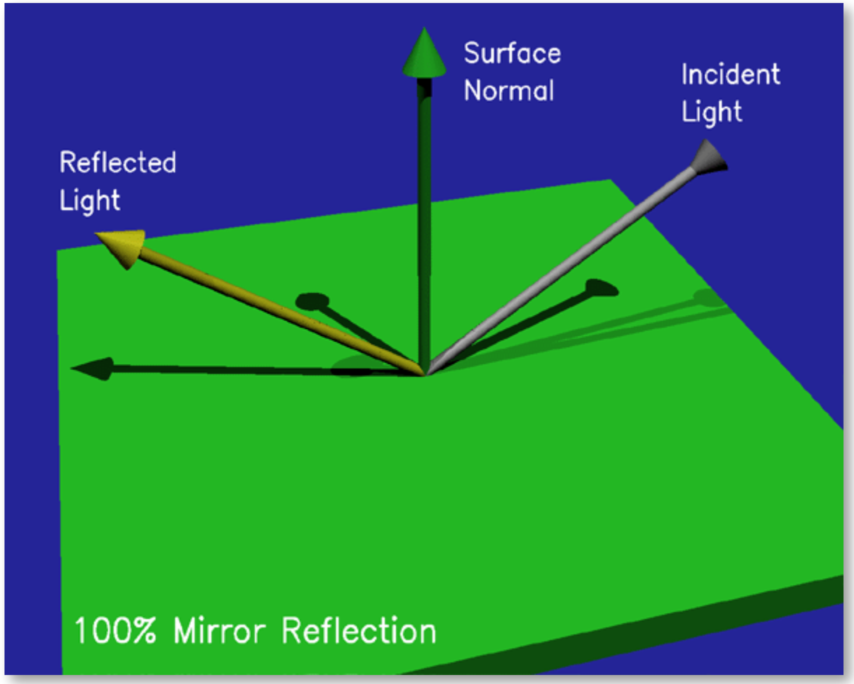
  - s = roughness: ∞ (1024) for a mirror, 2–3 for rough surface
  - $\cos \alpha = V \, . \, R$
  - $R = 2(\cos\theta)\, N - L$

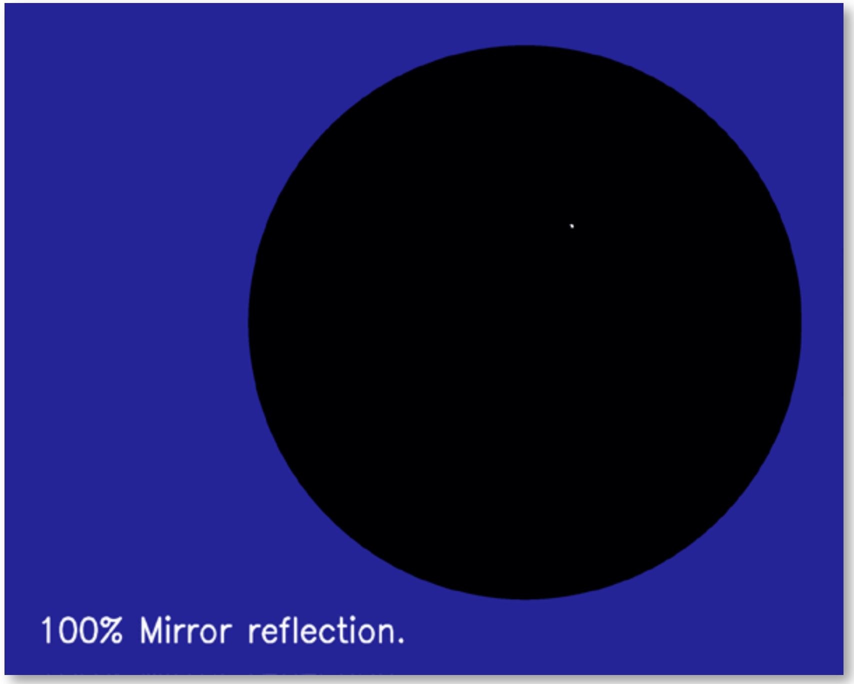
    $= 2(N \, . \, L)\, N - L$

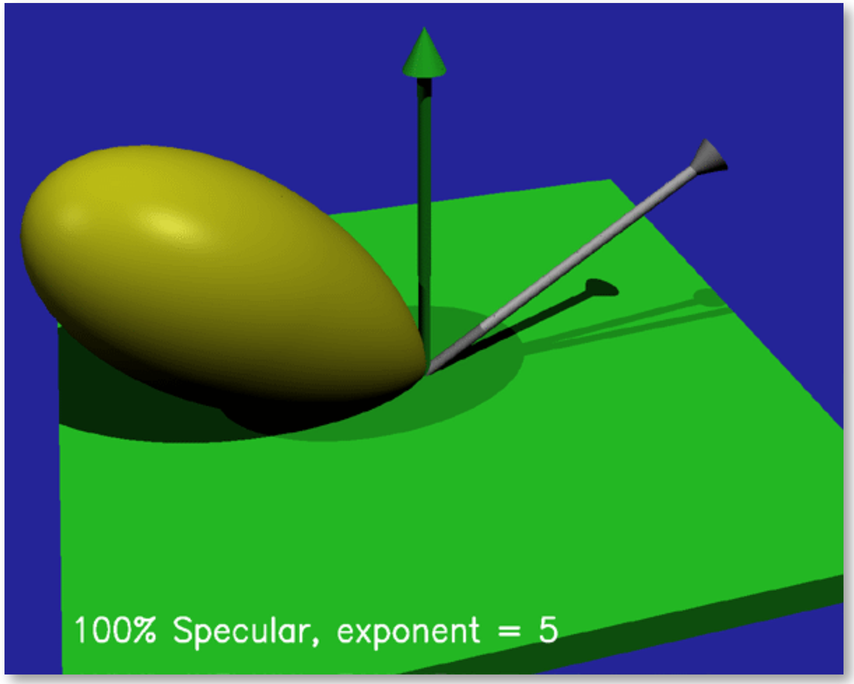


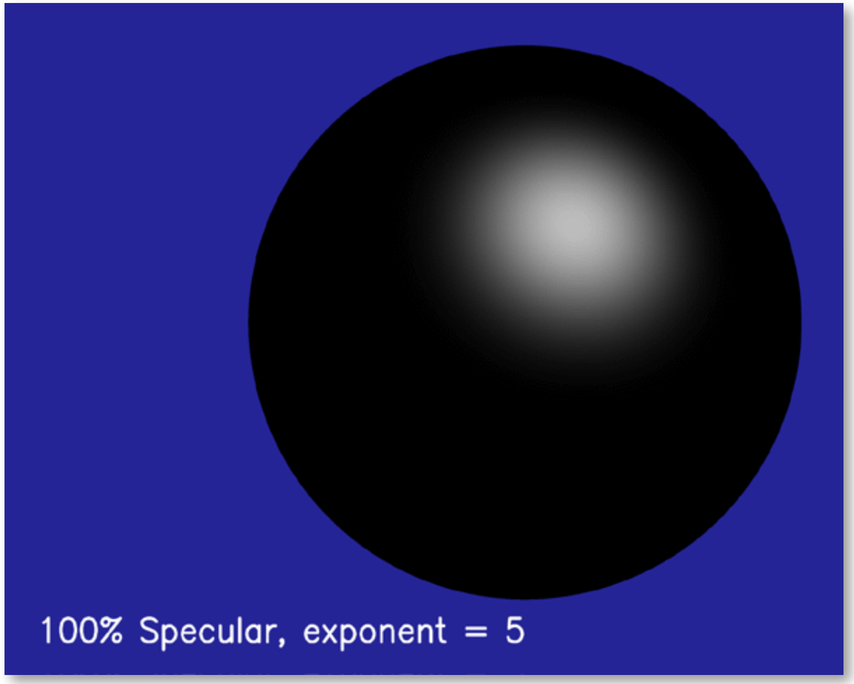
Phong model

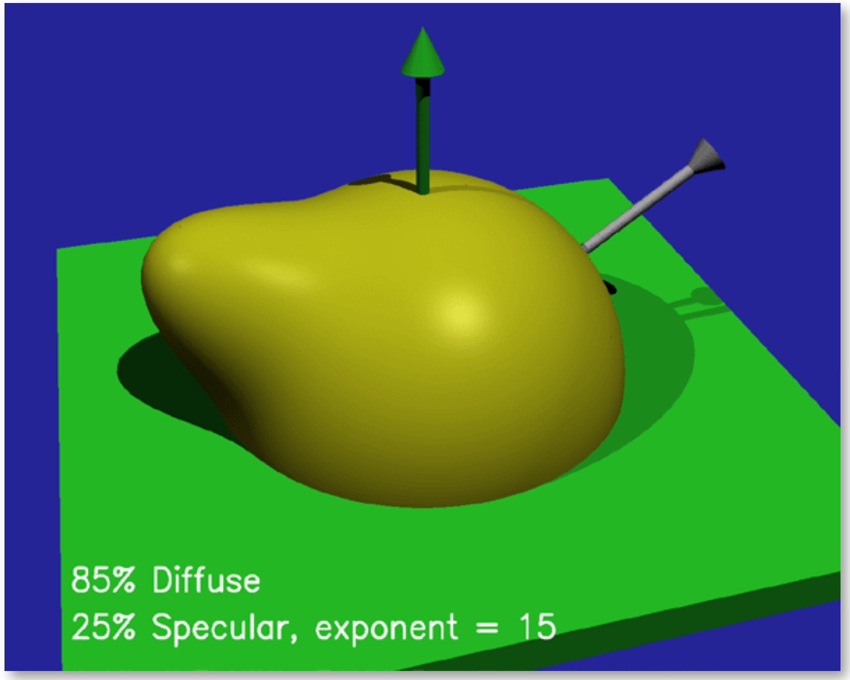


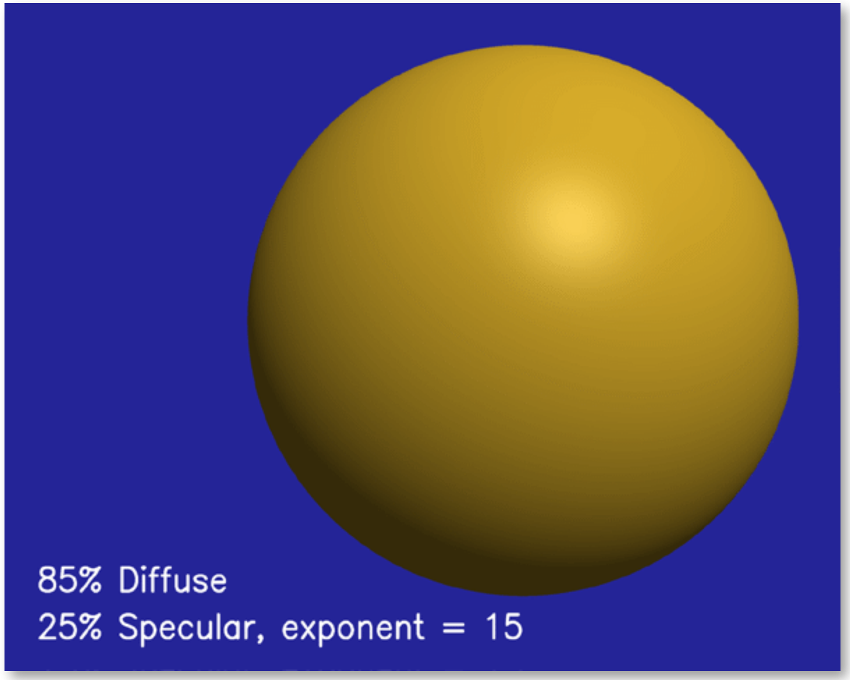

Surface
Normal
Incident
Light
Reflected
Light
100% Mirror Reflection

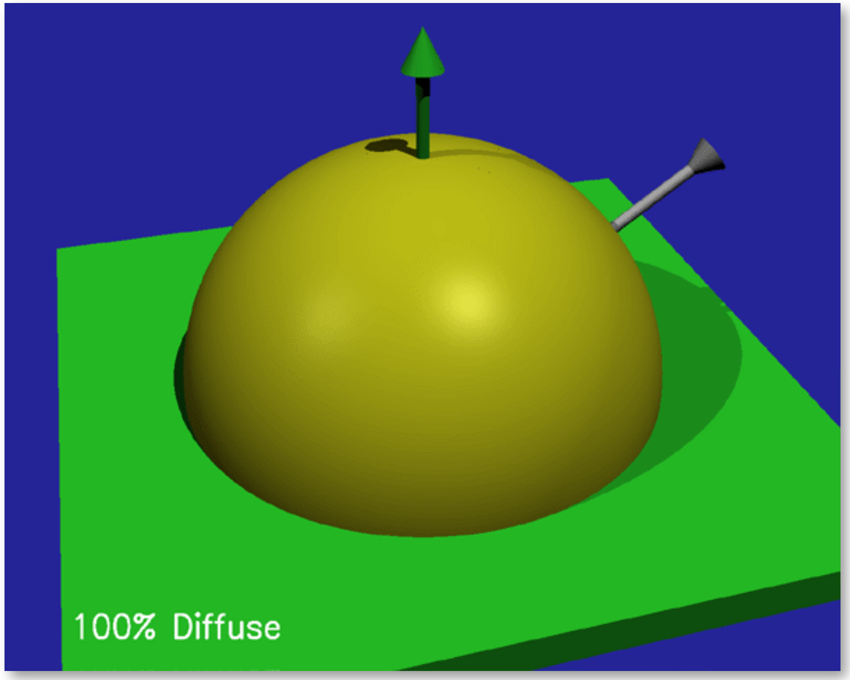

100% Mirror reflection.

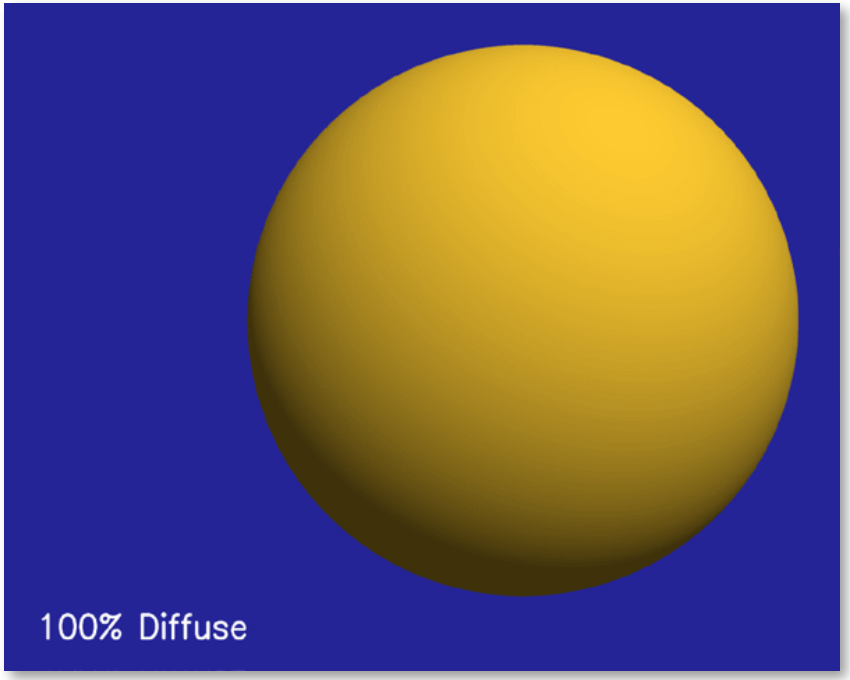

100% Specular, exponent = 5

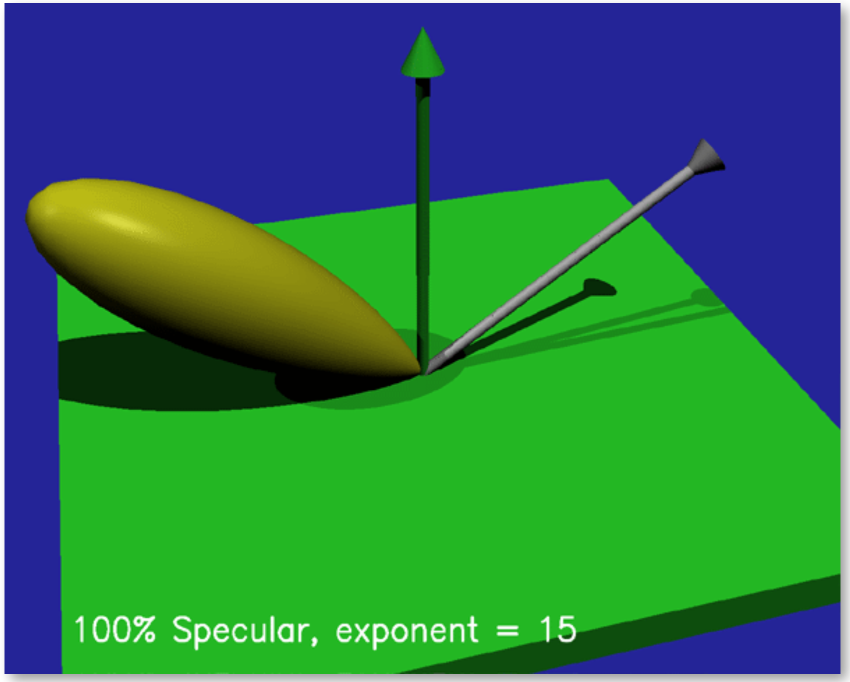

100% Specular, exponent = 5

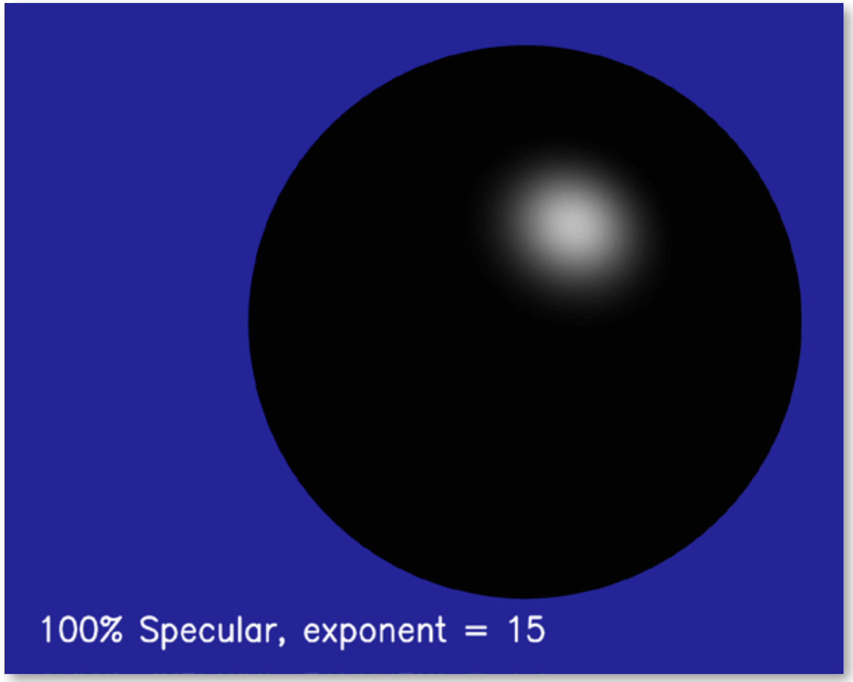

85% Diffuse
25% Specular, exponent = 15

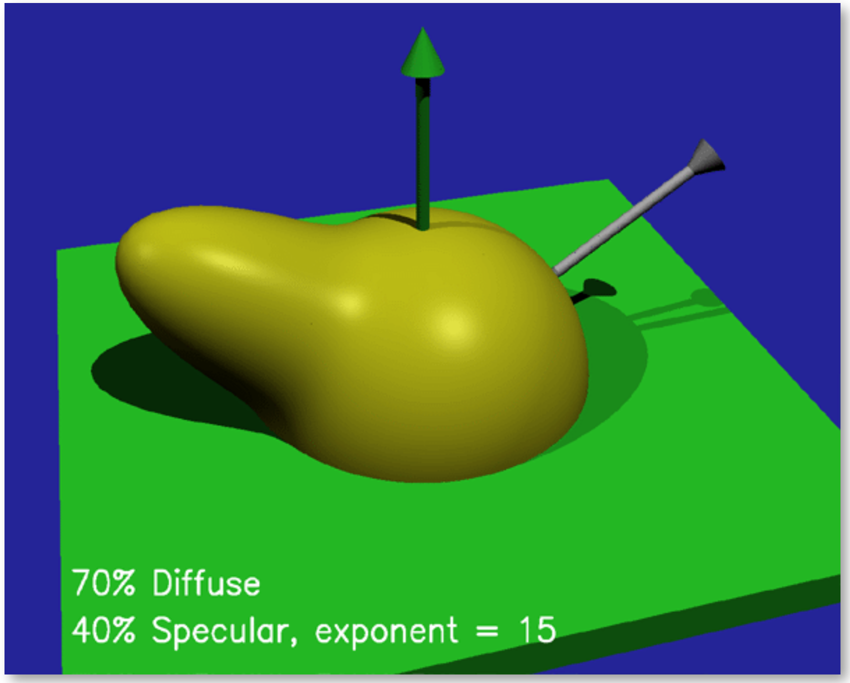

85% Diffuse
25% Specular, exponent = 15

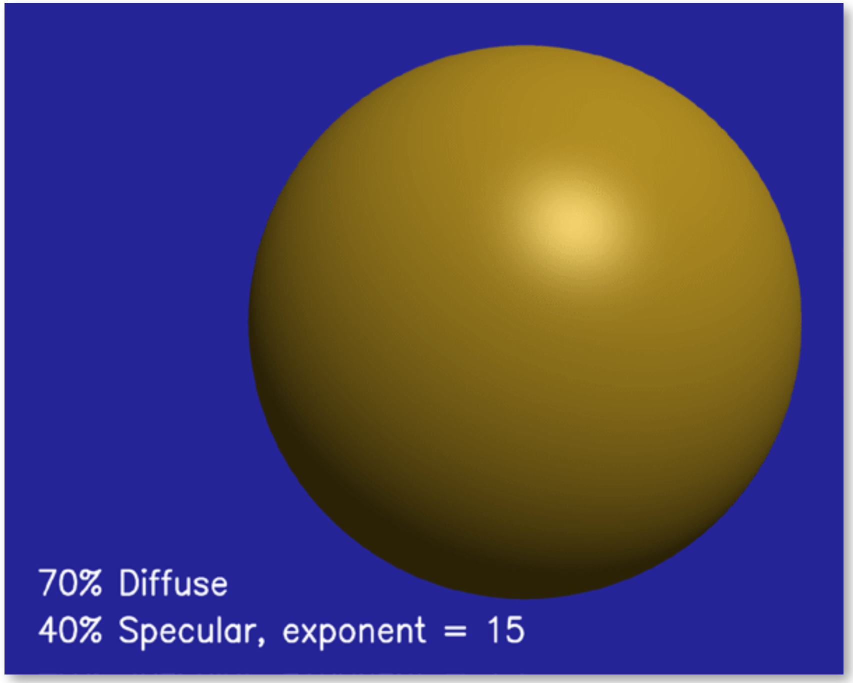

100% Diffuse


100% Diffuse


100% Specular, exponent = 15


100% Specular, exponent = 15

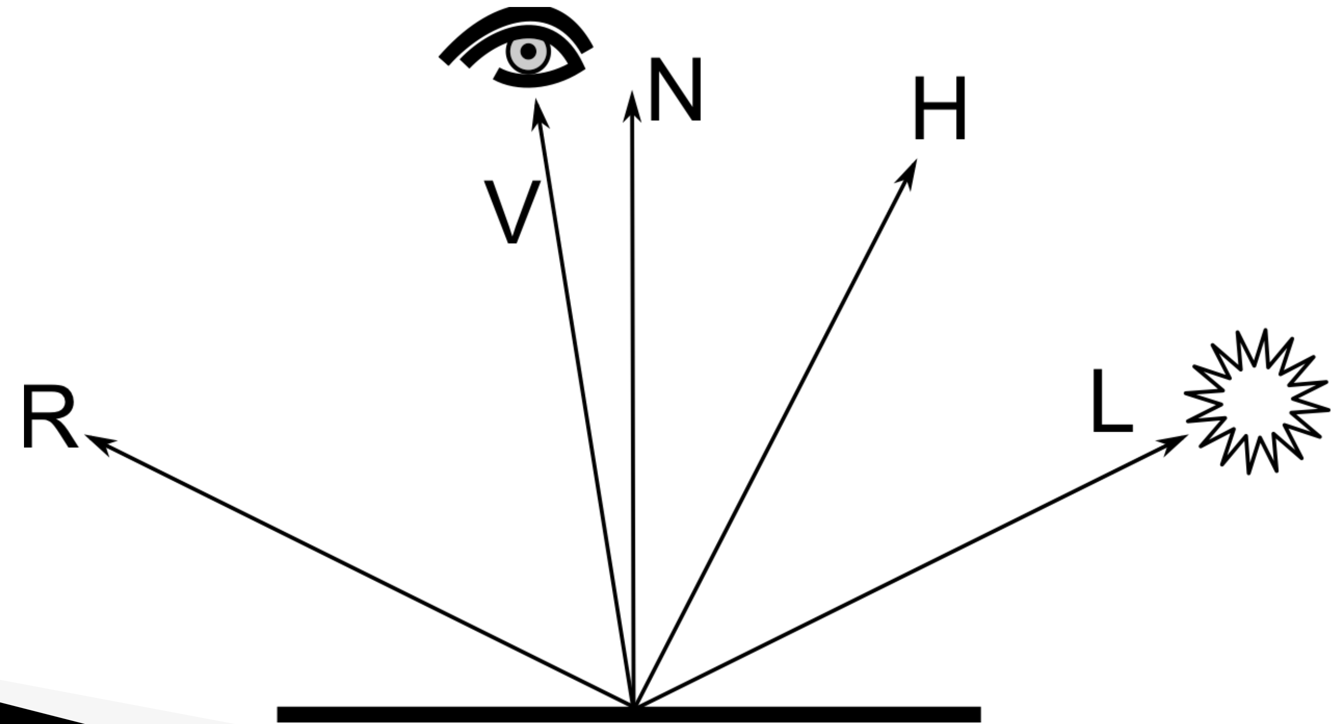

70% Diffuse
40% Specular, exponent = 15


70% Diffuse
40% Specular, exponent = 15

Blinn-Phong model [1977]

- Uses the half-vector: $\mathbf{h} = \frac{\mathbf{l} + \mathbf{v}}{\|\mathbf{l} + \mathbf{v}\|}$

- Reflected light is now: $I = \rho_s (\cos\theta)^n = \rho_s (\mathbf{h} \bullet \mathbf{n})^n$



Blinn-Phong or Phong

- Visually very similar
  - assuming you use $n = 4s$
  - slight differences for grazing directions
  - symmetric lobes for Phong, asymmetric for Blinn
- Blinn-Phong easier to code (?) (YMAMV)

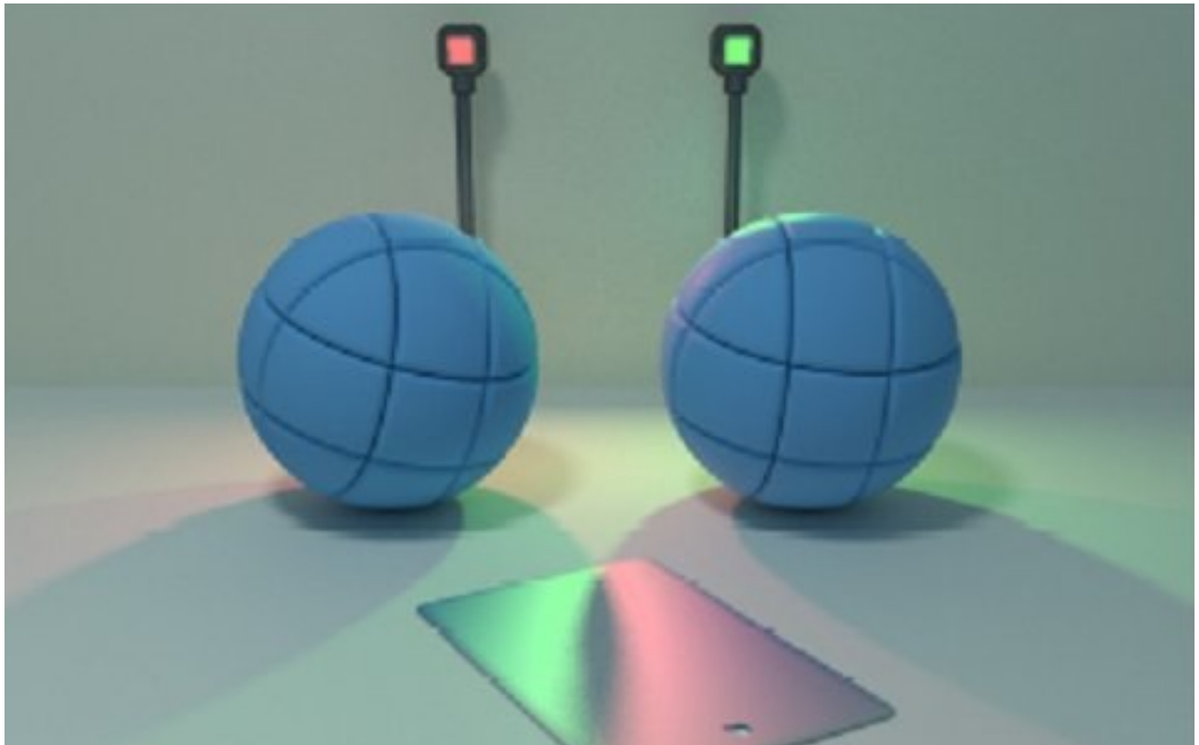
Lafortune Model

- "Improved Phong"
- "Perturb" the reflected direction vector

$$K = \rho_s \cdot [C_{xy}(l_x v_x + l_y v_y) + C_z l_z v_z]^n$$

$$\mathbf{l} = (l_x, l_y, l_z)$$

$$\mathbf{v} = (v_x, v_y, v_z)$$

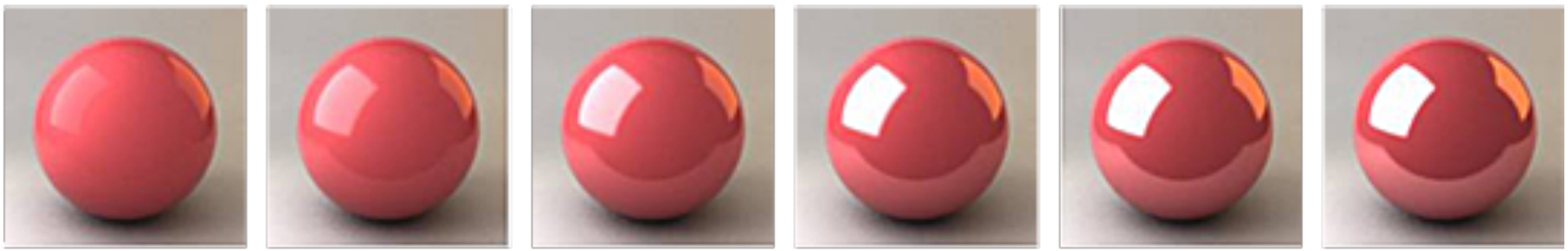


Fresnel coefficients

Experiment by Lafortune, Foo, Torrance & Greenberg (Siggraph 1997)

Fresnel Coefficients

- Reflection coefficients varying with viewing angle
- Interface between 2 materials, with different index:
  - complex (metals)
  - real (transparent / dielectric)



Fresnel Coefficients

- Depends on material index, polarization
- Complicated formula

$$R_p = \left(\frac{n_1 \cos\theta_t - n_2 \cos\theta_i}{n_1 \cos\theta_t + n_2 \cos\theta_i}\right)^2 \qquad R_s = \left(\frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t}\right)^2$$

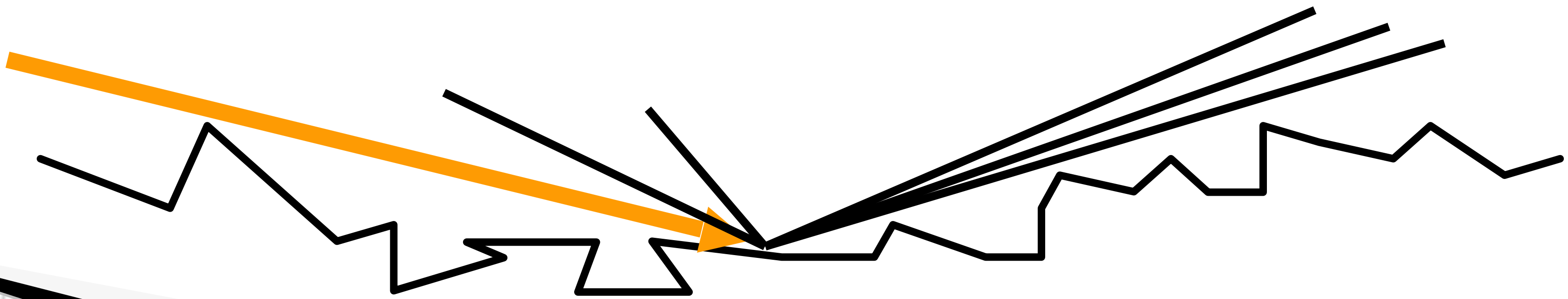
- Schlick Approximation:

$$F = F_0 + (1 - F_0)(1 - \cos\theta)^5$$

$$\cos\theta = (\mathbf{v} \bullet \mathbf{h})$$

Cook-Torrance-Sparrow model [1967]

- Surface is made of micro-facets
  - small specular mirrors
- Light reaching a facet:
  - Reflected, masked, shadowed
  - Statystical analysis, depending on micro-facets orientation probability distribution
  - A bit more complex. Good approximation.



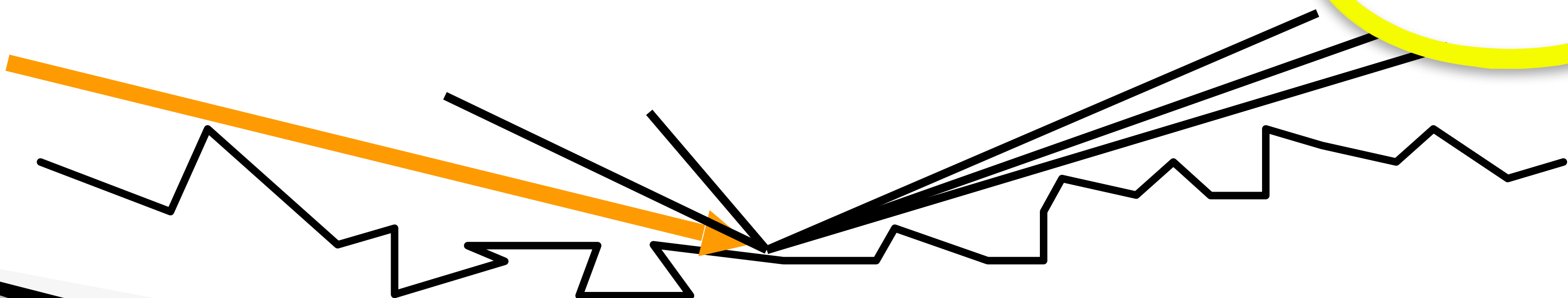
Cook-Torrance-Sparrow Model [1967]

- Product of 3 terms
  - Fresnel coefficient (F)
  - Distribution of facets orientation (D)
  - Masking and shadowing (G)

$$K = \frac{\rho_s}{\pi} \frac{DG}{(N \cdot L)(N \cdot V)} Fresnel(F_0, V \cdot H)$$

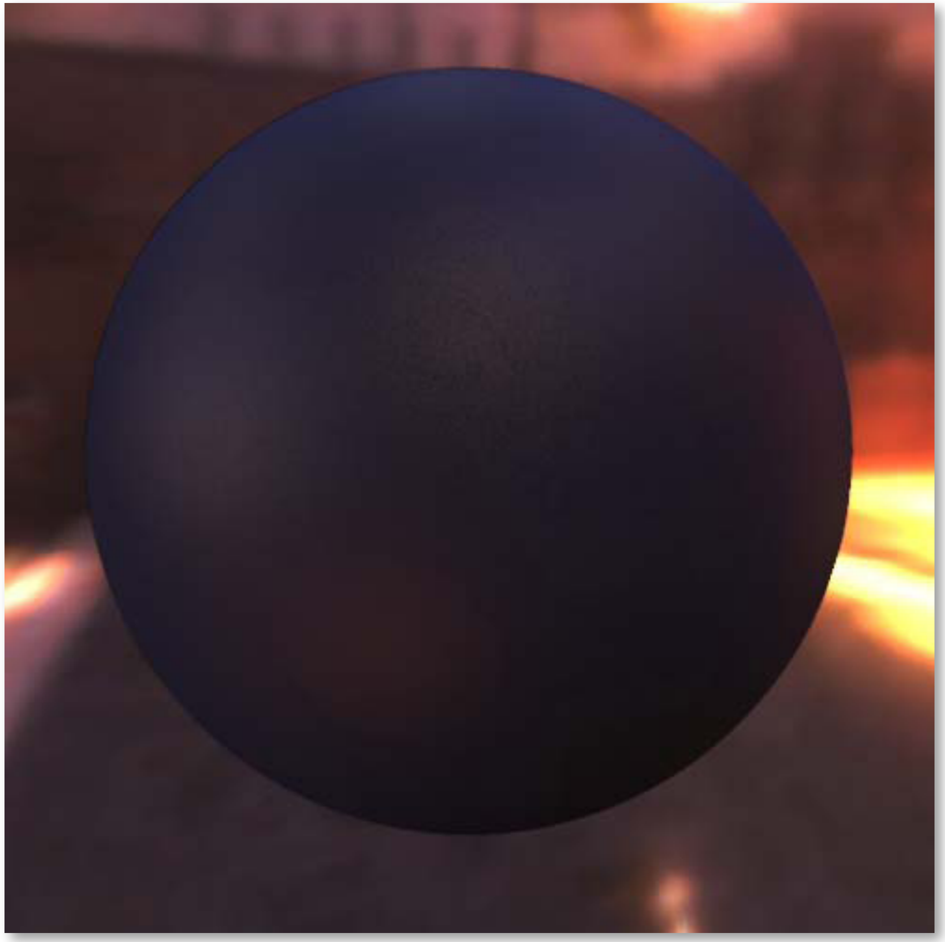
A gaussian distribution!

$$G = min\{1, \frac{2(N \cdot H)(N \cdot V)}{(V \cdot H)}, \frac{2(N \cdot H)(N \cdot L)}{(V \cdot H)}\} \text{ and } D = \frac{1}{m^2 \cos^4 \delta} e^{-[(tan\delta)/m]^2}$$

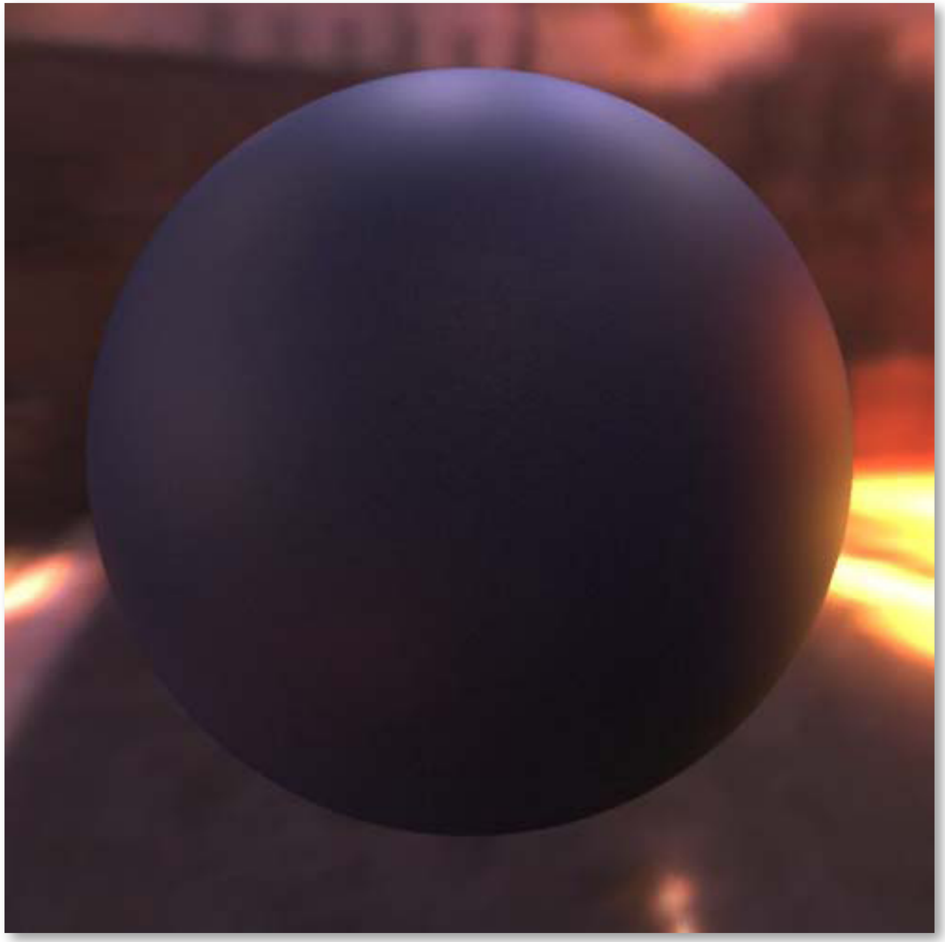


Cook-Torrance-Sparrow Model [1967]

Acquired data

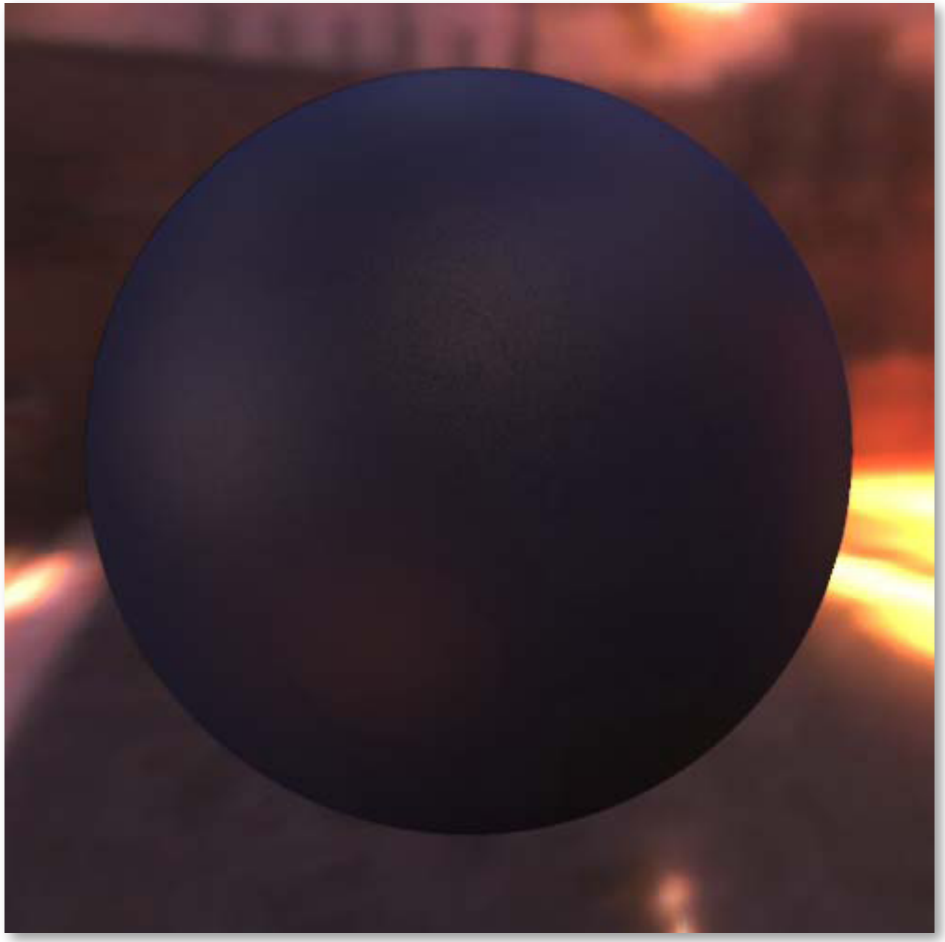


Phong model

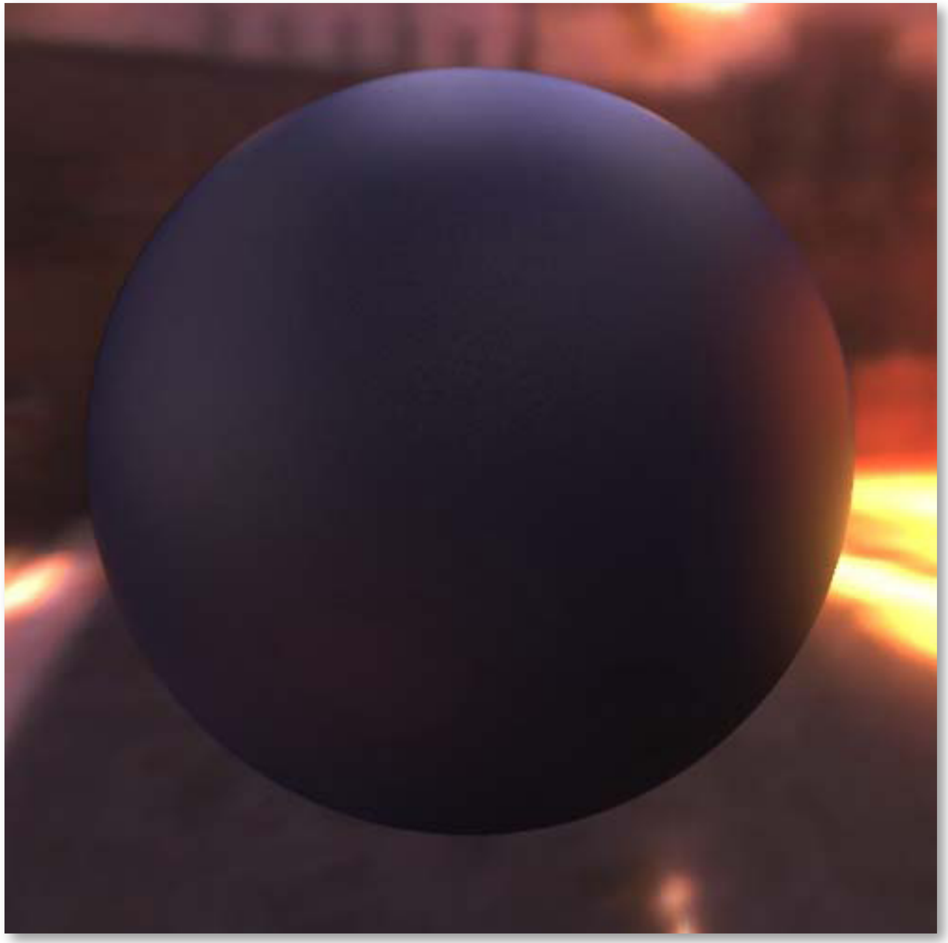


Cook–Torrance–Sparrow Model [1967]

Acquired data

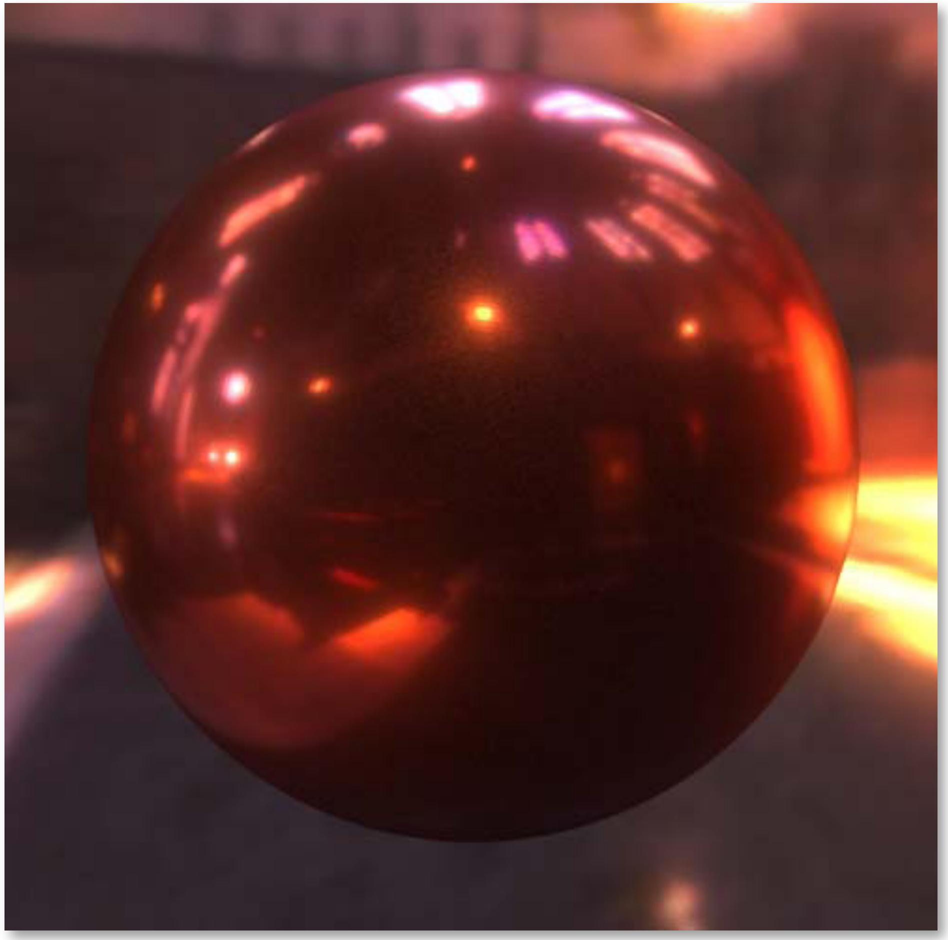


Cook-Torrance model

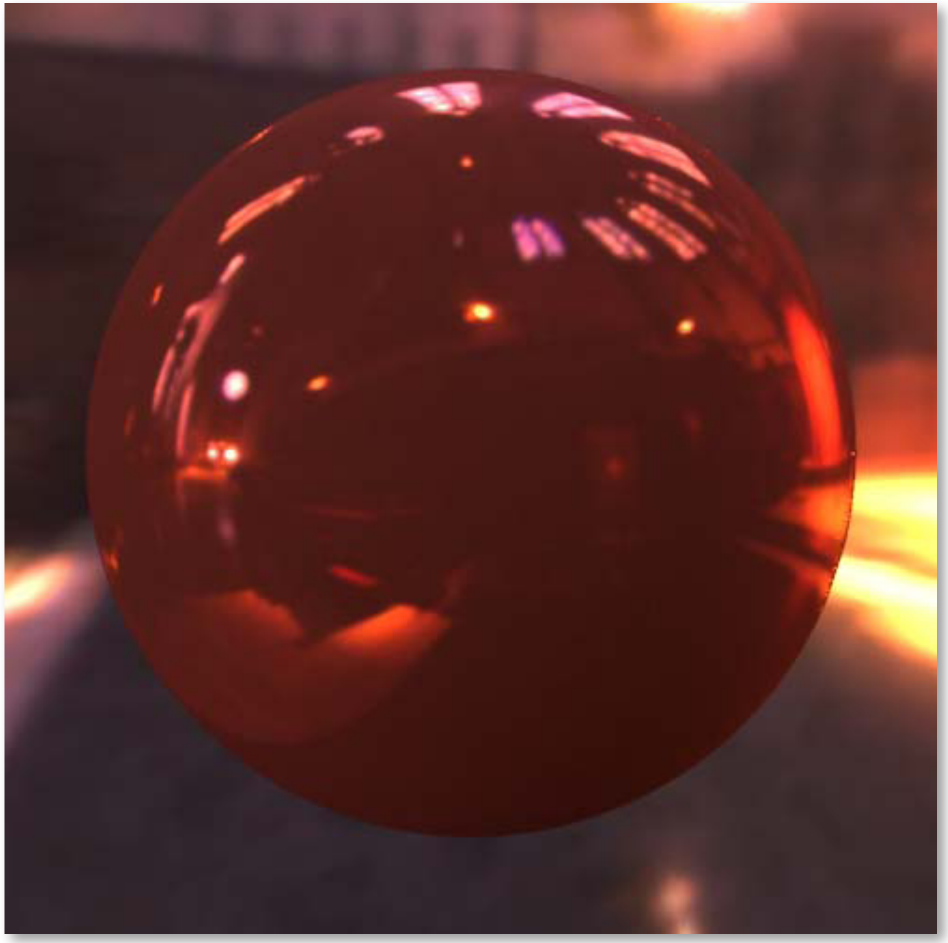


Cook–Torrance–Sparrow Model [1967]

Acquired data

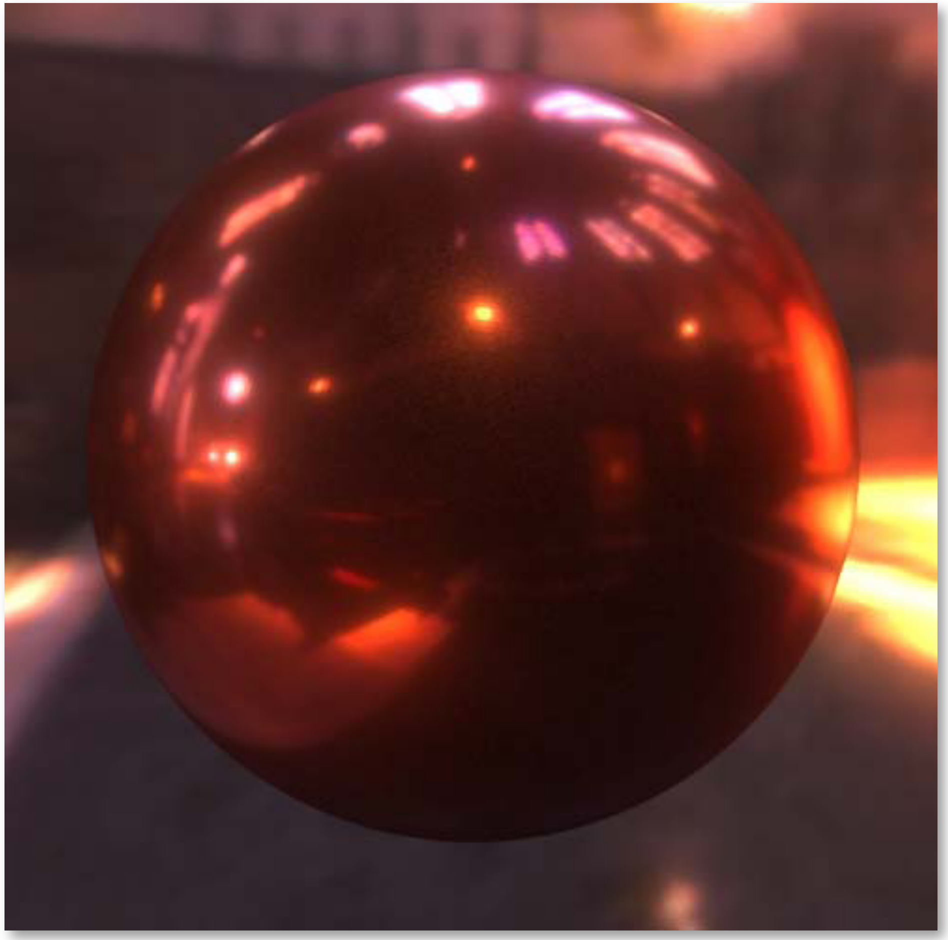


Cook-Torrance model

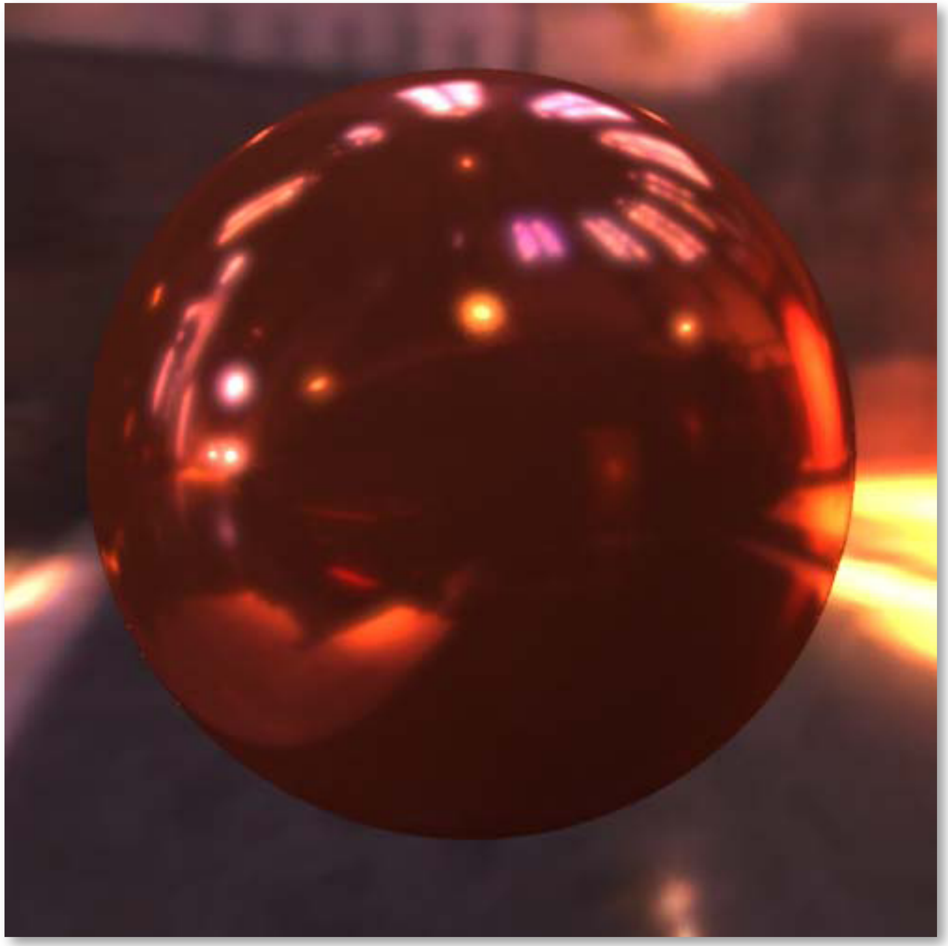


Cook-Torrance-Sparrow Model [1967]

Acquired data



Cook-Torrance, 2 lobes



Spatially varying

- Map an image on the object surface
  = change BRDF parameters at every point
- Texture mapping

BRDF only

Textured

Spatially varying

- BTF : Bidirectional Texture Function
  - 6D : 2D in space + 4D for the BRDF
  - Acquisition, compression and editing complex

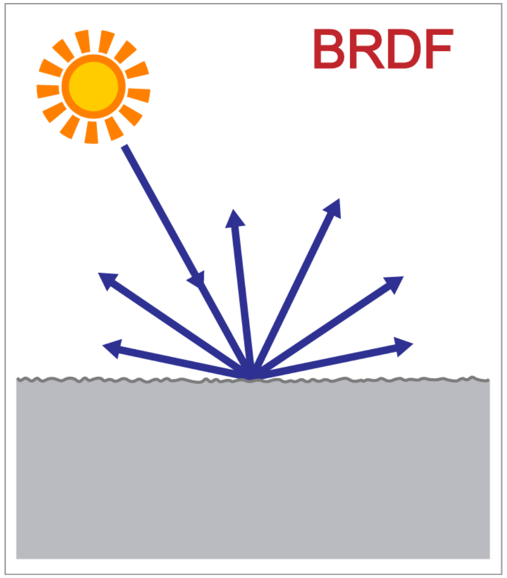
Texture

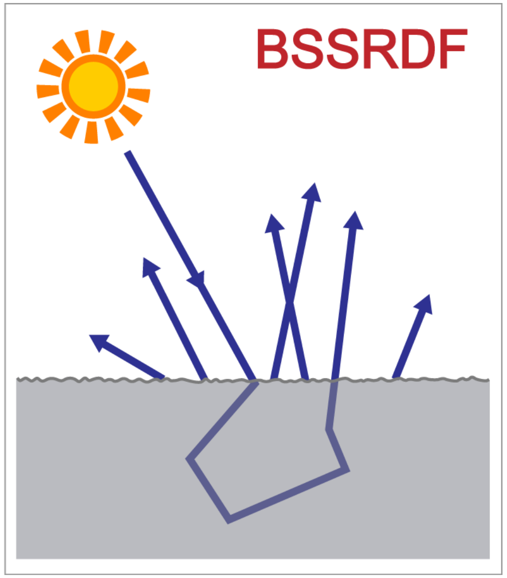
BTF

Jan Kautz et al. 2007

Volumetric variations

- BSSRDF : Bidirectional surface scattering reflectance distribution function
  - 8D function
  - Subsurface Scattering





Ravi Ramamoorthi

Volumetric variations

- BSSRDF : Bidirectional surface scattering reflectance distribution function

BRDF

BSSRDF

Henrik Wann Jensen, 2001

Volumetric variations

- BSSRDF : Bidirectional surface scattering reflectance distribution function

BRDF

BSSRDF

Henrik Wann Jensen, 2001