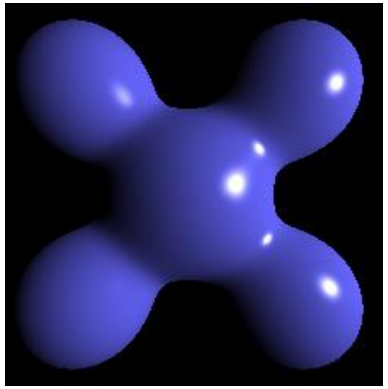
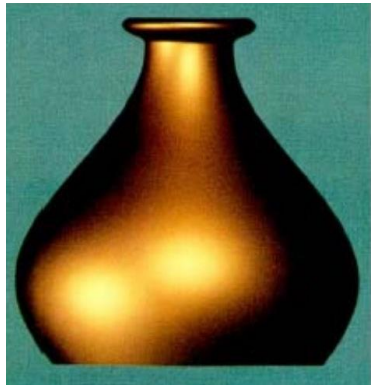
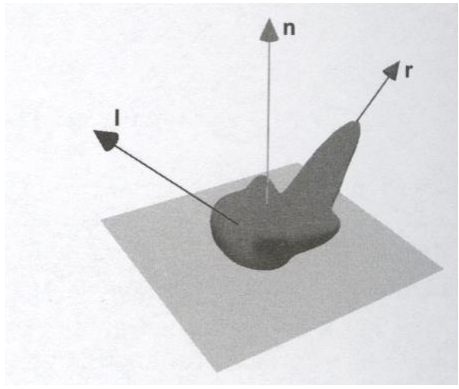
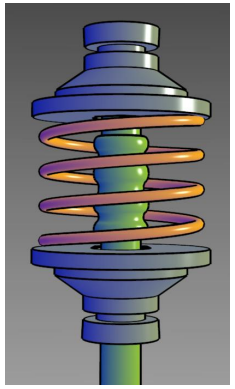






Computer Graphics

Advanced Illumination Models and BRDFs

Tobias Isenberg

informatics mathematics Inria

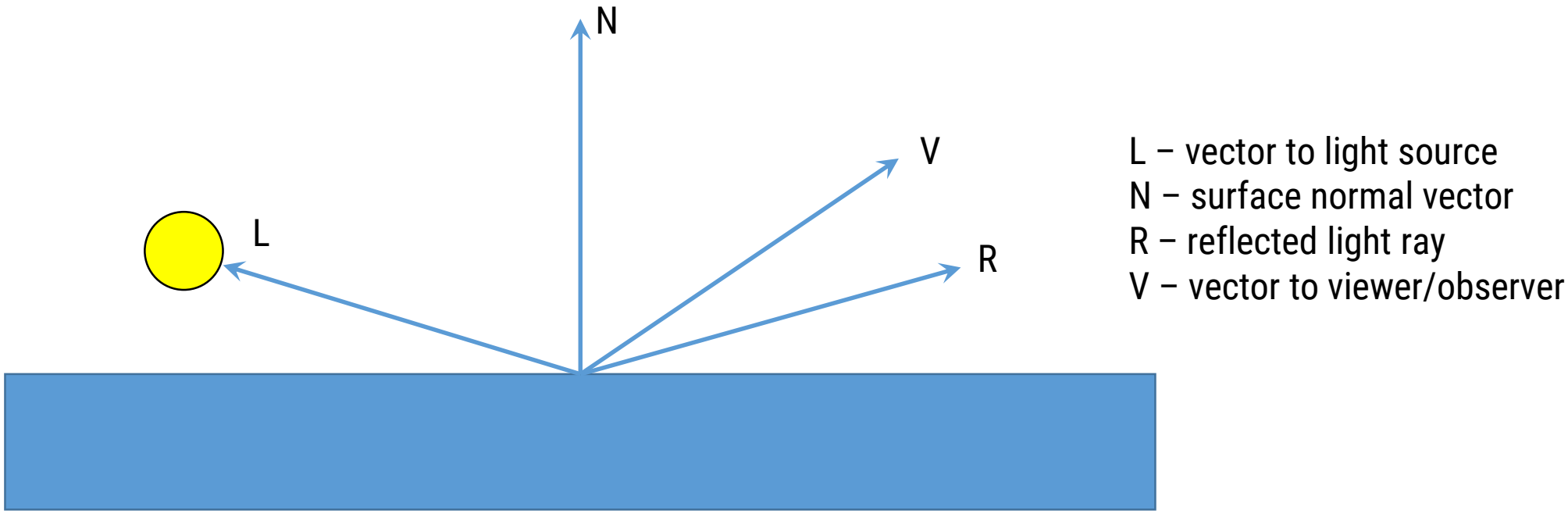
Overview

- going beyond Phong's illumination model
- advanced heuristics
  - Blinn-Phong model
  - Cook-Torrance model
  - Gooch model
- model based on real data: BRDF

Re-Cap: Phong's Model of Illumination

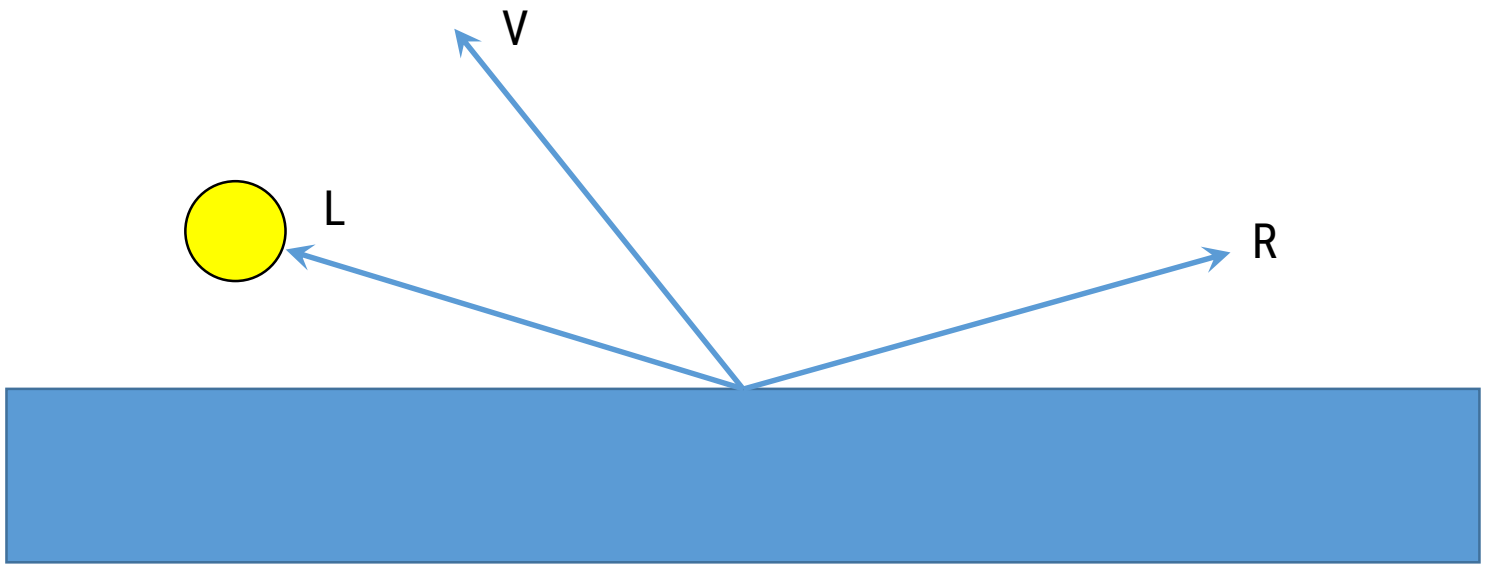
- combination of ambient, diffuse, and specular light

$$I_{Pong} = L \cdot k_a + \frac{1}{a + bd + cd^2}(L \cdot k_d \cdot (L \cdot N) + L \cdot k_s \cdot (R \cdot V)^e)$$



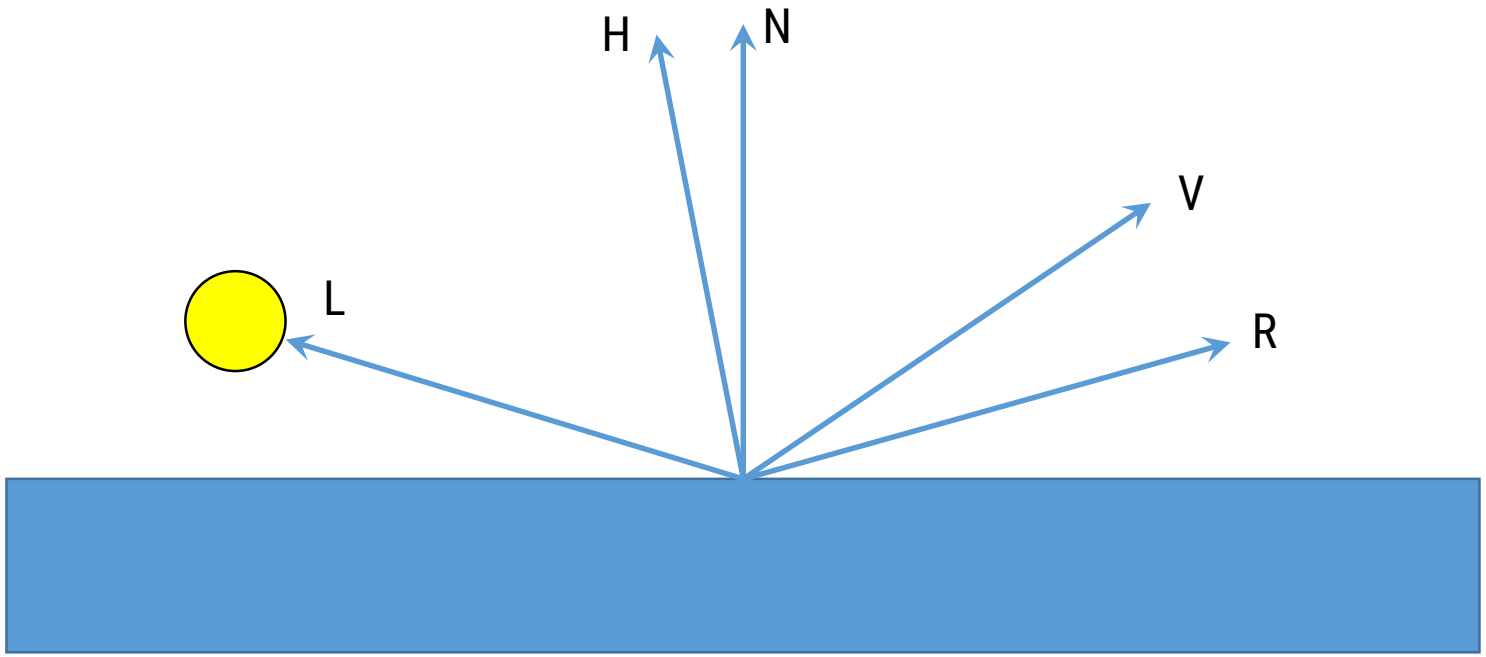
Blinn-Phong Model

- limitation of Phong model:
  - no specular reflectance if angle between V and R > 90 degrees
  - some amount of light should still arrive (microfacet model)



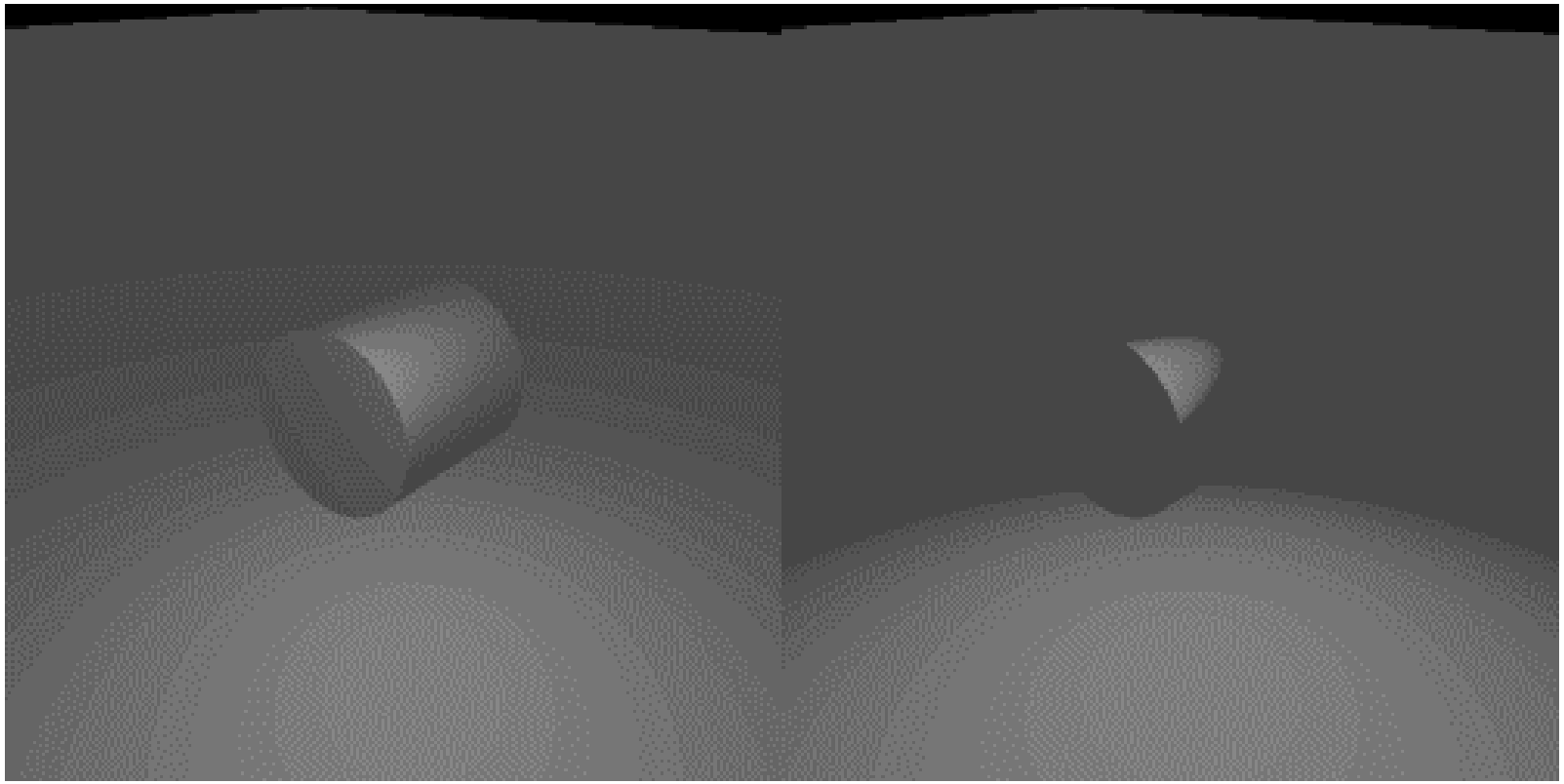
Blinn-Phong Model

- idea – use H: half-way vector between L and V
  - compute specular component as $(H \bullet N)^e$
  - $H \bullet N > 0$, even if if angle between V and R > 90 degrees ($V \bullet R < 0$)



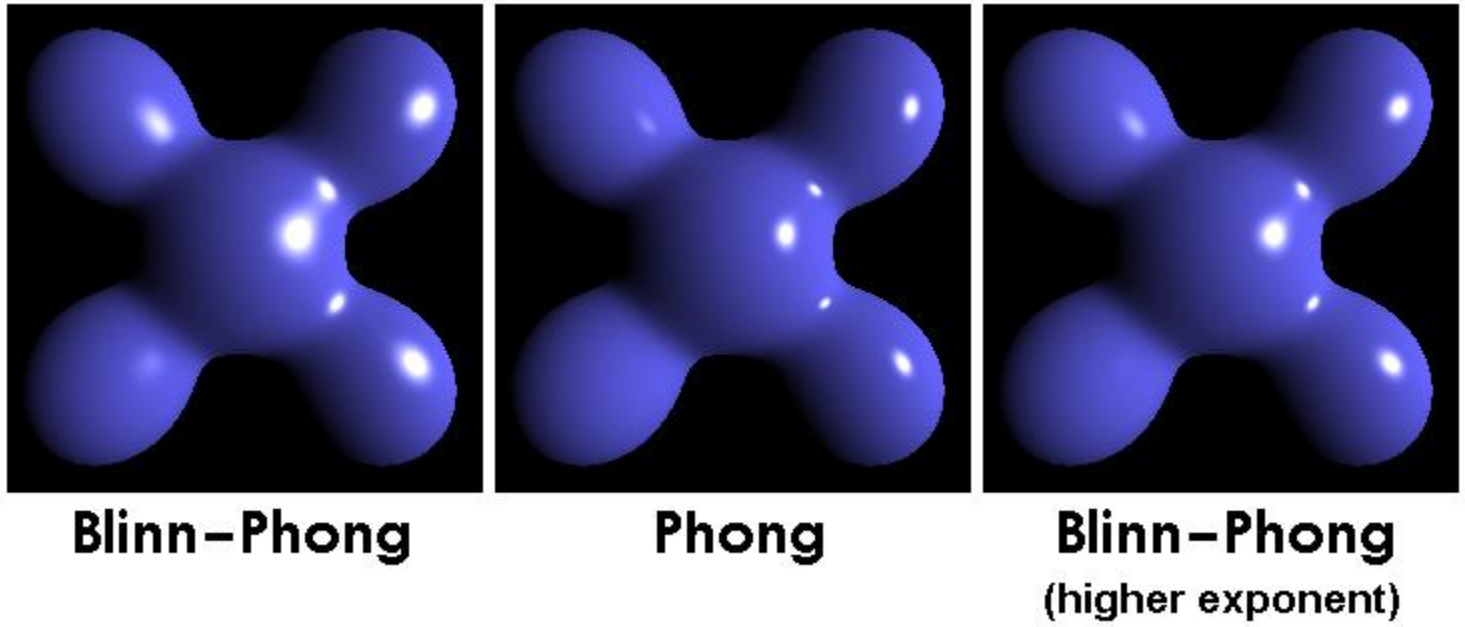
Blinn-Phong Model

- result:



[Jason L. McKesson]

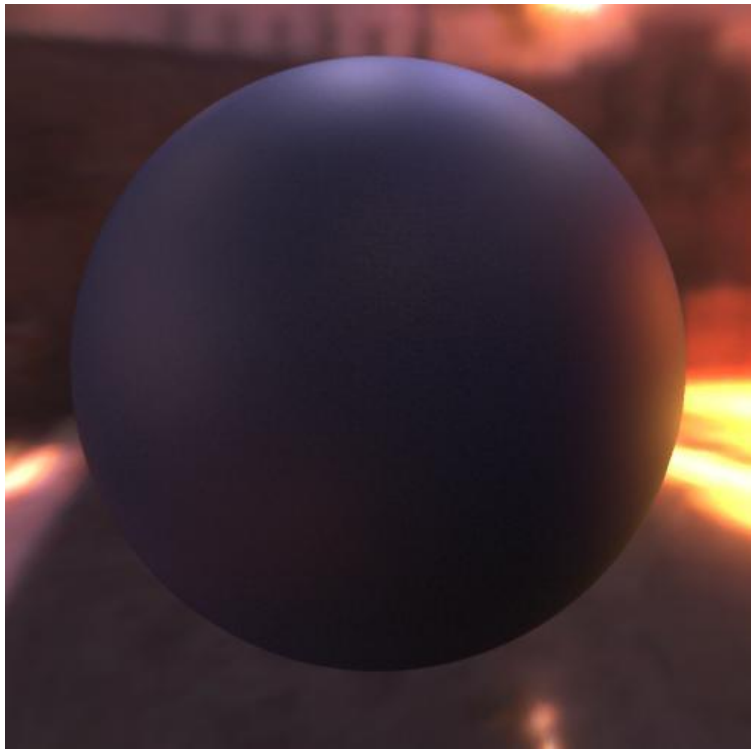
Blinn-Phong Model



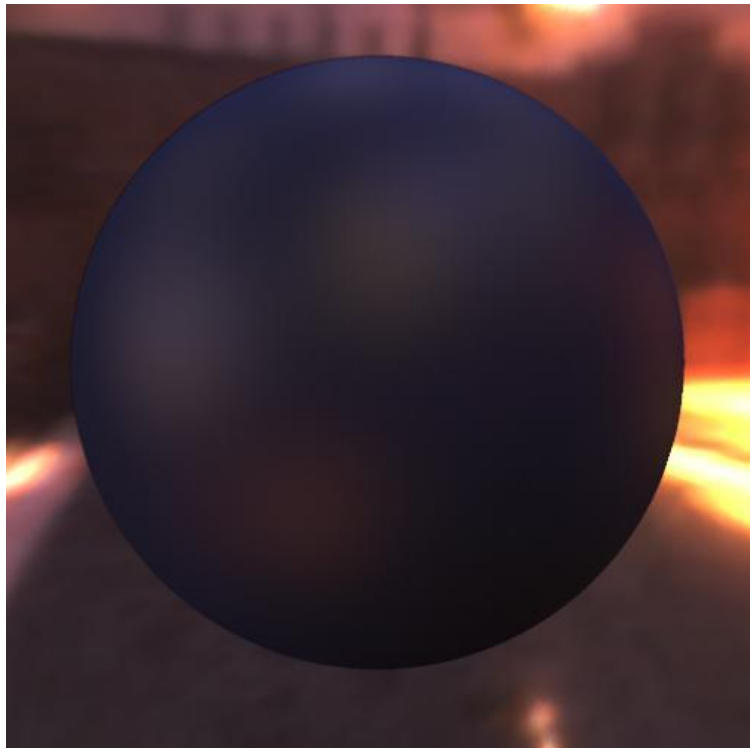
- due to smaller angles between H and N compared to R and V, the produced hightlights are normally wider
- adjusted exponents to address this point

Blinn-Phong Model

- quality actually empirically shown to be better than Phong



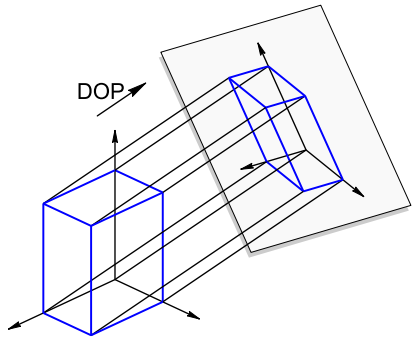
acquired data

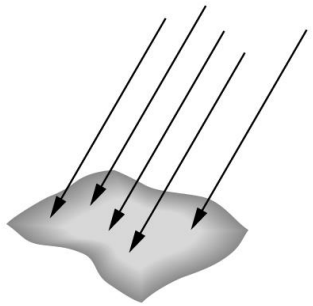


Blinn-Phong model

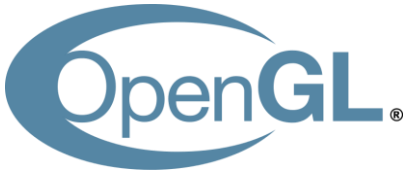
[Ngan et al, 2004]

Blinn-Phong Model



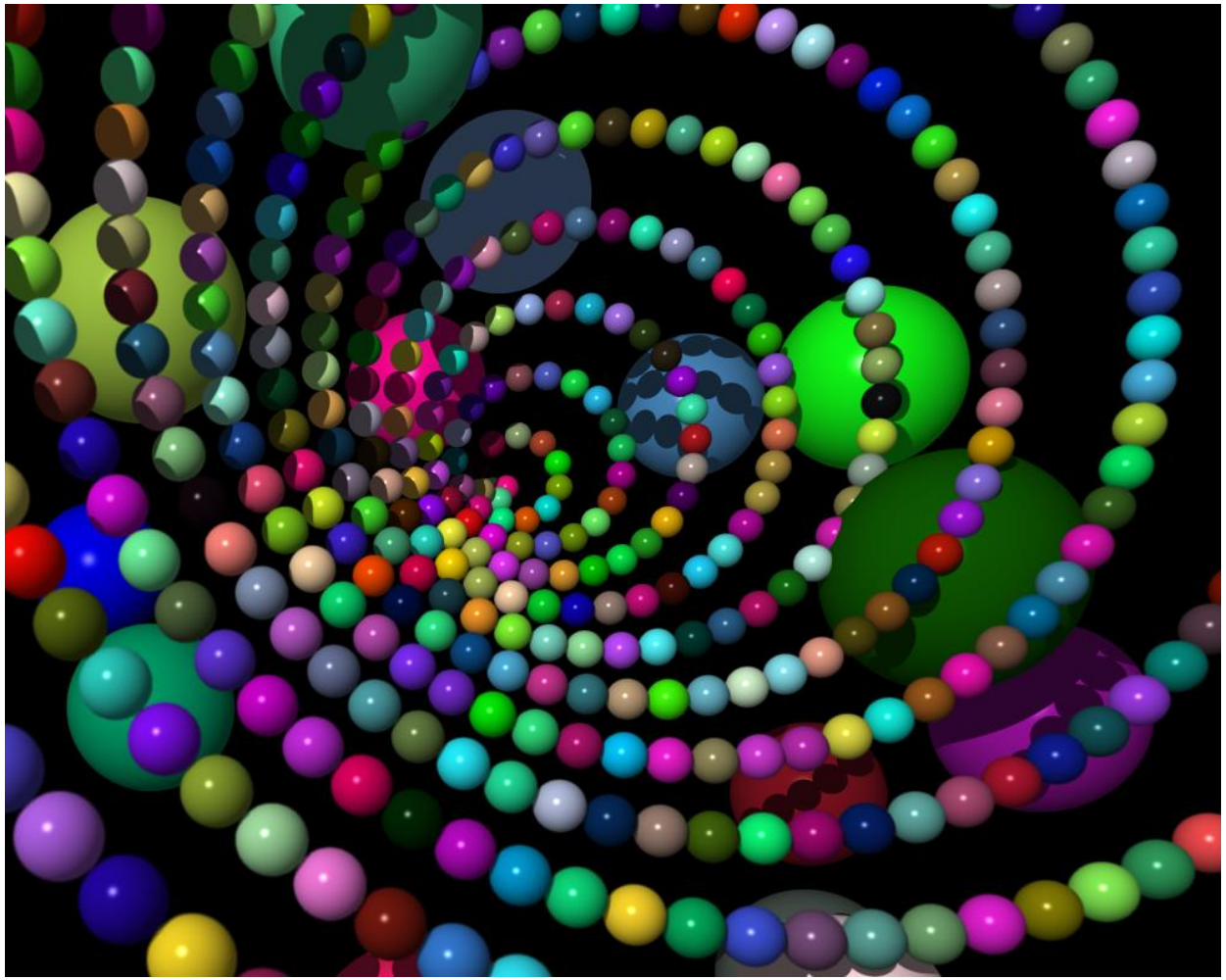


- performance equivalent to normal Phong model
- higher performance for lights and viewers at infinity
  - cameras become orthographic cameras: V is constant
  - lights become directional lights: L is constant
  - thus H is also constant
- the Blinn-Phong model was thus the one used in early (non-programmable) OpenGL pipelines;
  i.e., not the Phong model



Status so far

- limited representation of material properties: plastic look
- limited consideration of light frequency



Marijn Stollenga

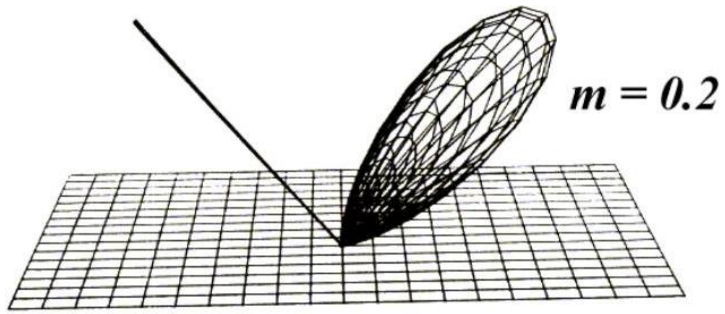
Cook-Torrance Model

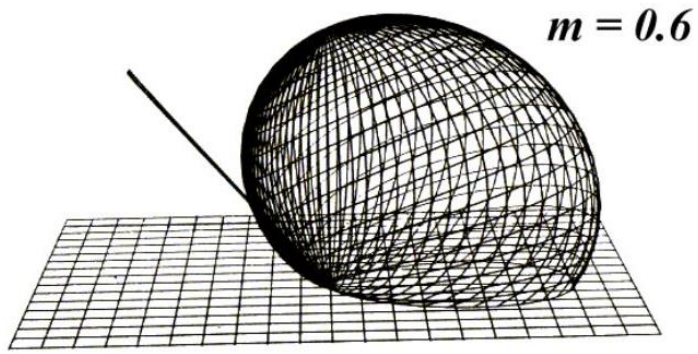
- limited consideration of materials in previous models
- goal:
  - consider wavelength-dependent behavior
  - represent wider range of materials
  - focus on specular part of illumination (to combine with diffuse/ambient terms)
- use of three aspects:
  - microfacet distribution
  - geometry attenuation
  - Fresnel reflection

Torsten Bätge

Cook-Torrance: microfacet distribution

- improvement over simple exponent for specular highlight
- uses a model (Beckmann distribution) with roughness term *m*

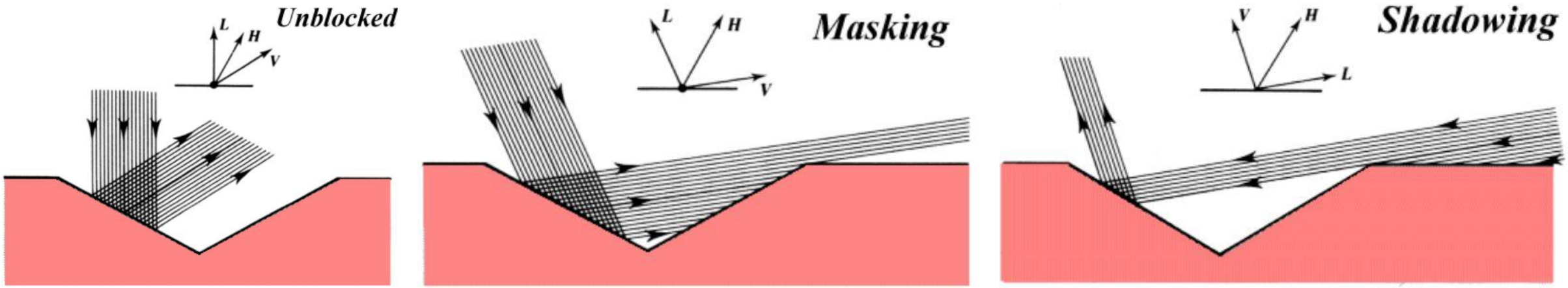




m = 0.1 0.3 0.6 0.8 1.0

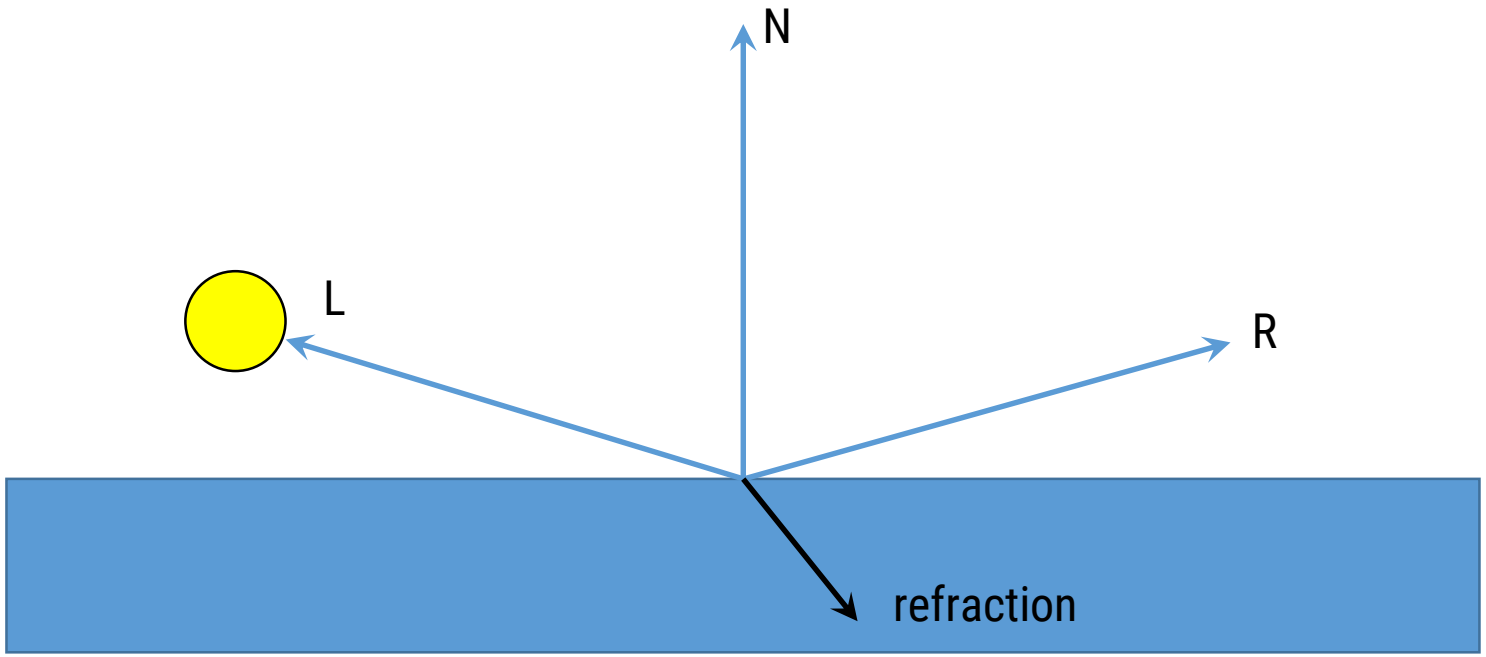
Cook-Torrance: geometry attenuation

- amount of effective light is affected by microfacet masking and shadowing

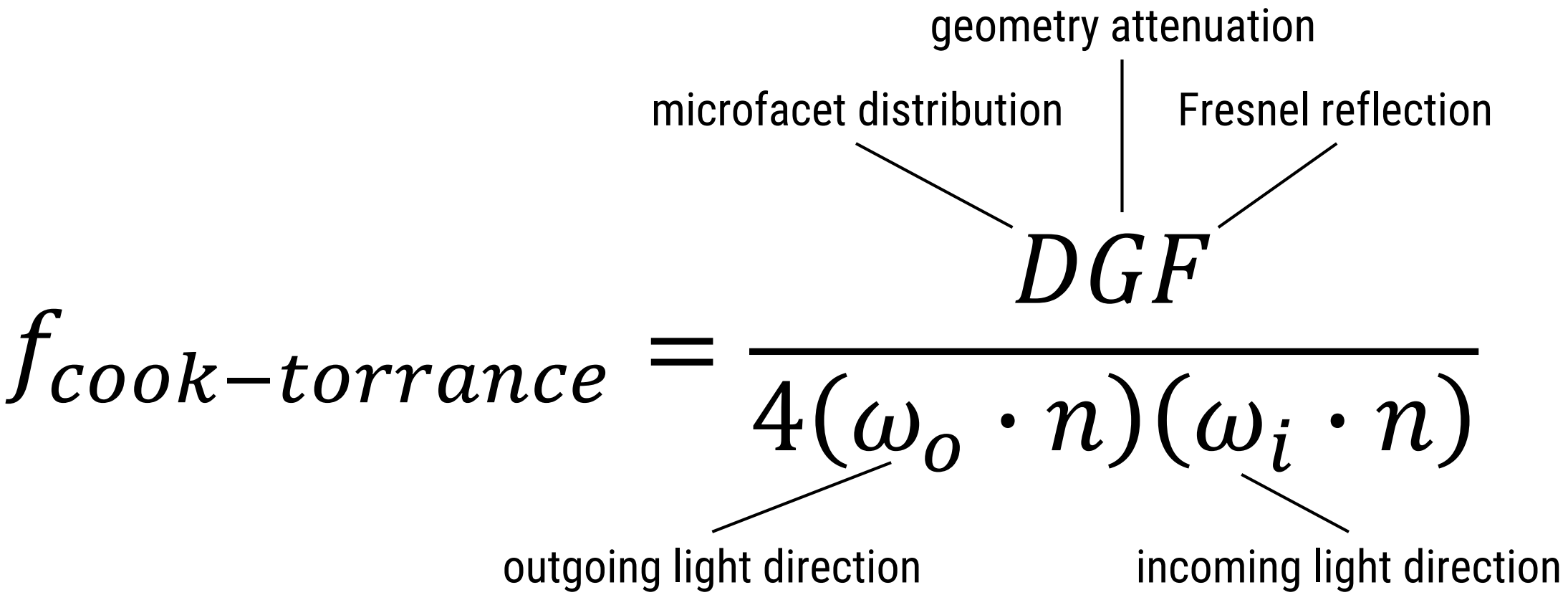


Cook-Torrance: Fresnel reflection

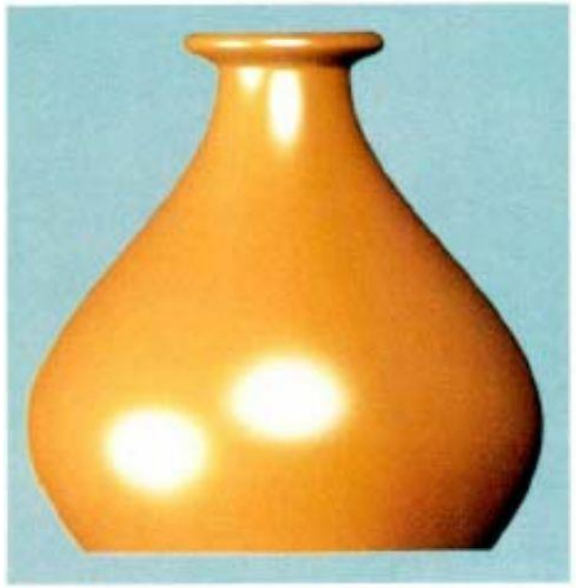
- reflection
  - depends on angle, absorption, and refraction
  - is different based on light polarization



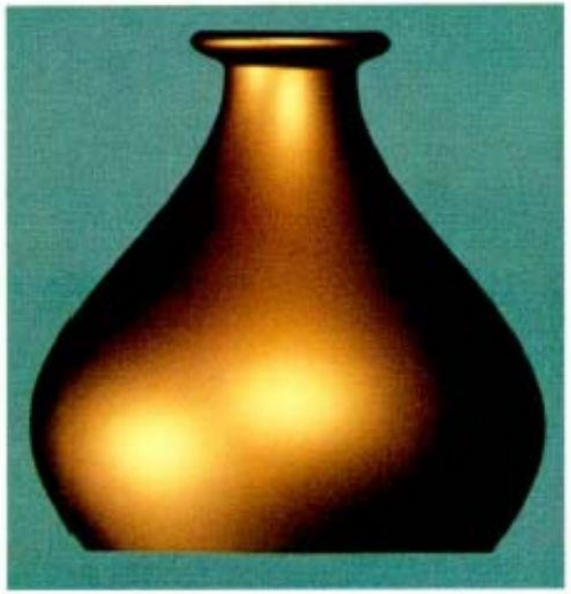
Cook-Torrance Model



Cook-Torrance Model: Results



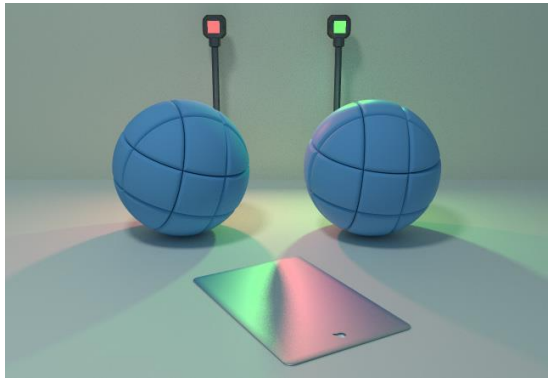
Phong

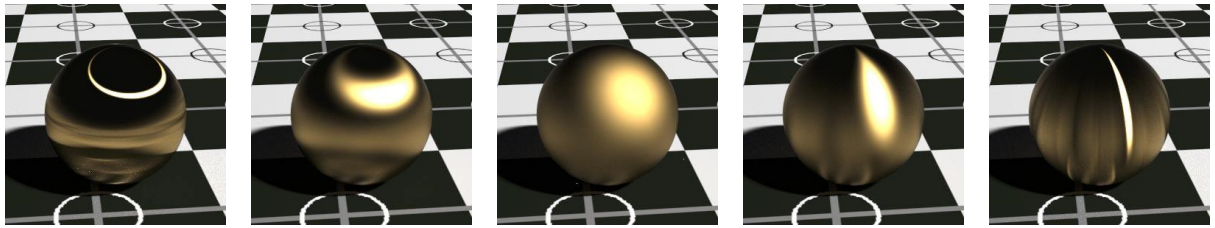


Cook-Torrance

Other Heuristics for Photorealism

- Ward (1992):
  - focus on anisotropic reflection
  - based on empirical data
- Lafortune (1997):
  - generalization of Phong's model
  - based on empirical data
- Ashikhmin-Shirley (2000):
  - focus on anisotropic reflection
  - model for BRDF computation



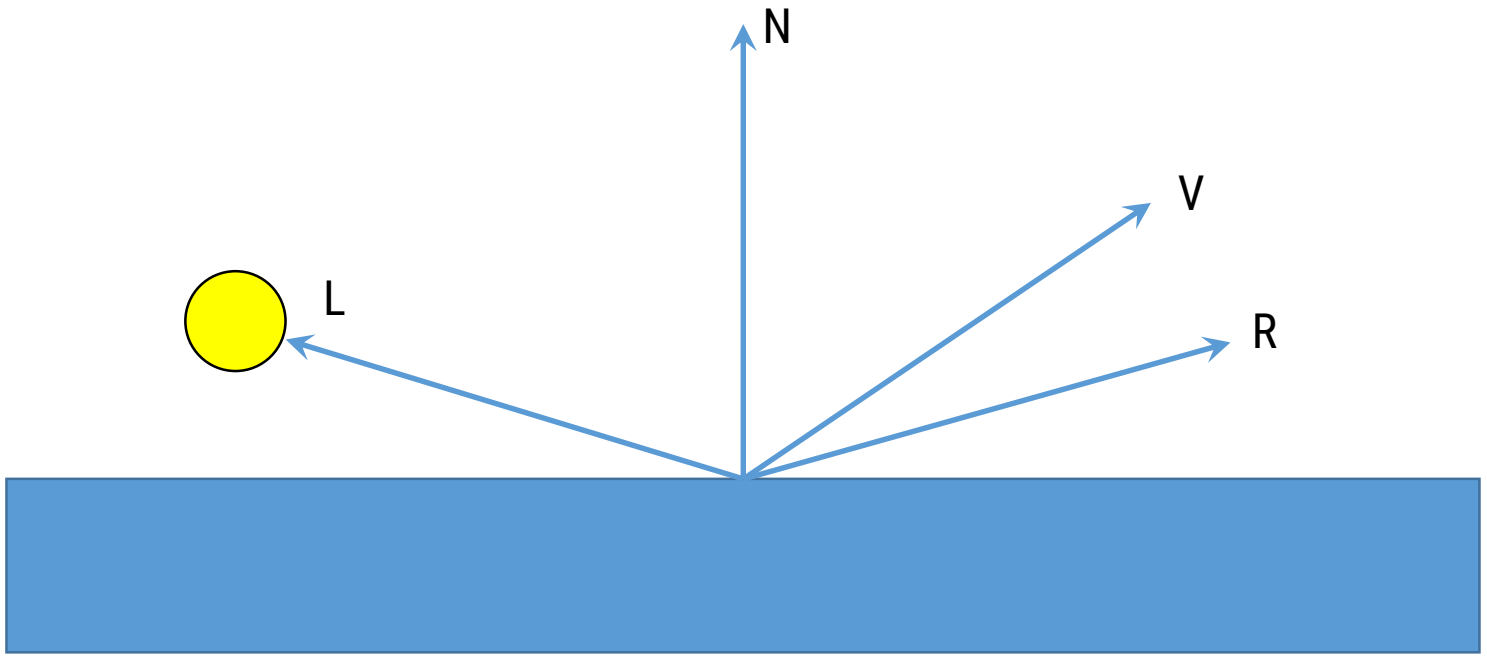


Status so far

- more or less detailed heuristics of light reflection behavior
- we know that reflection depends on
  - amount of incoming light
  - direction of incoming light (w.r.t. orientation of the surface)
  - direction of outgoing light (w.r.t. orientation of the surface)
  - material properties (potentially with anisotropic behavior)
  - frequency of the light

BRDFs

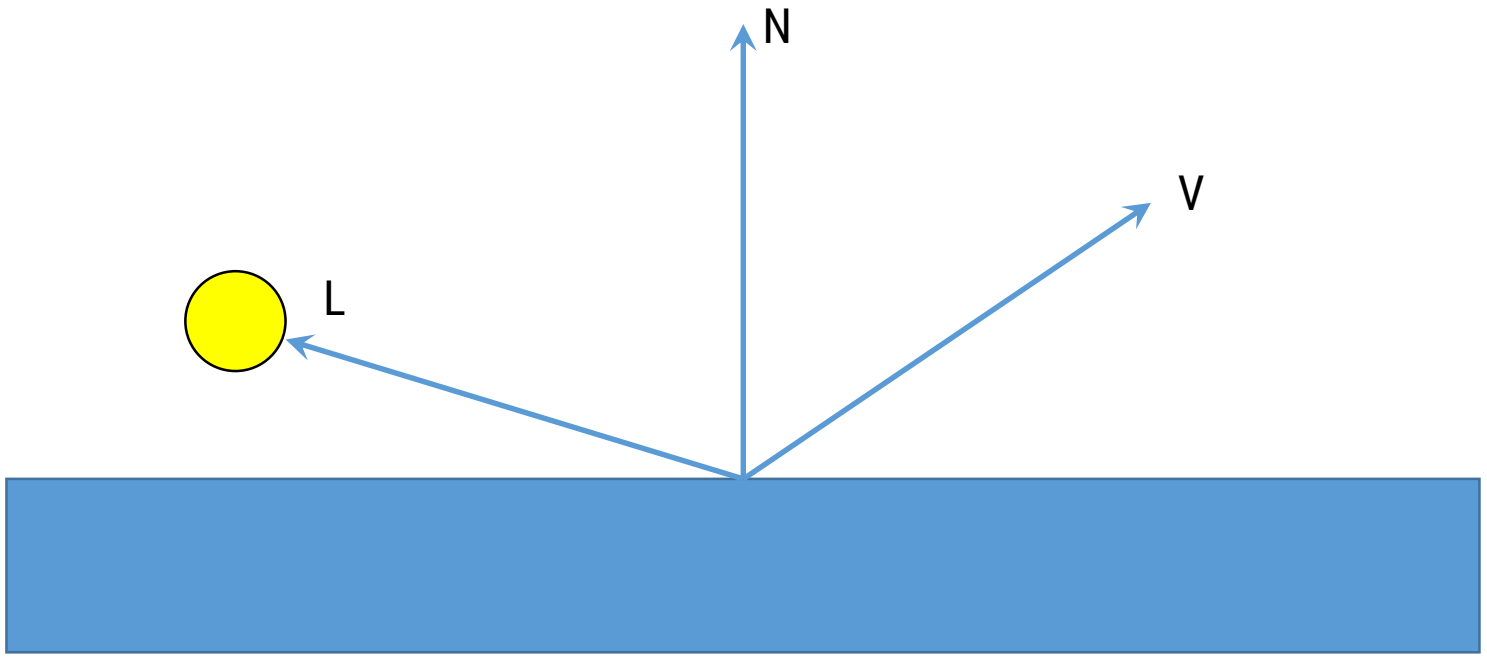
- Bi-directional Reflection Distribution Function
- generic view of the direct reflection behavior at a point



L – vector to light source
N – surface normal vector
R – reflected light ray
V – vector to viewer/observer

BRDFs

- Bi-directional Reflection Distribution Function
- generic view of the direct reflection behavior at a point



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BRDFs

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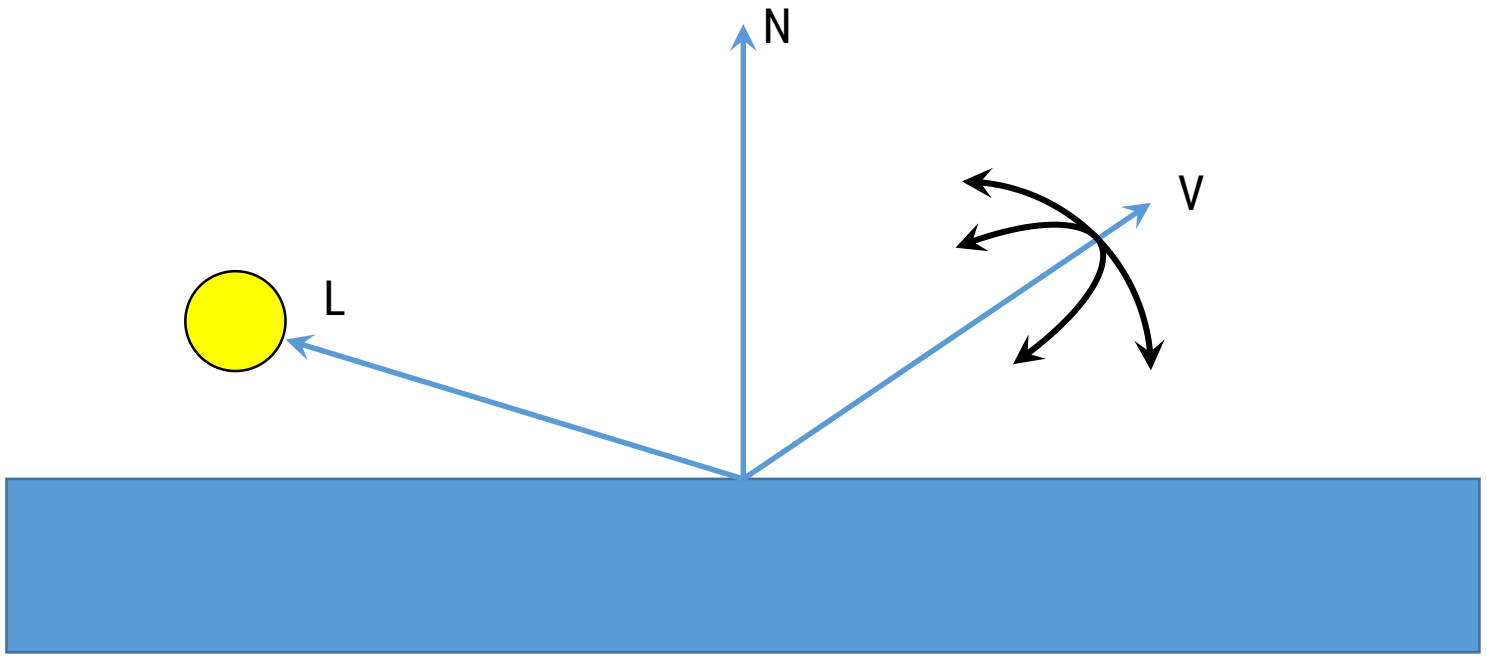

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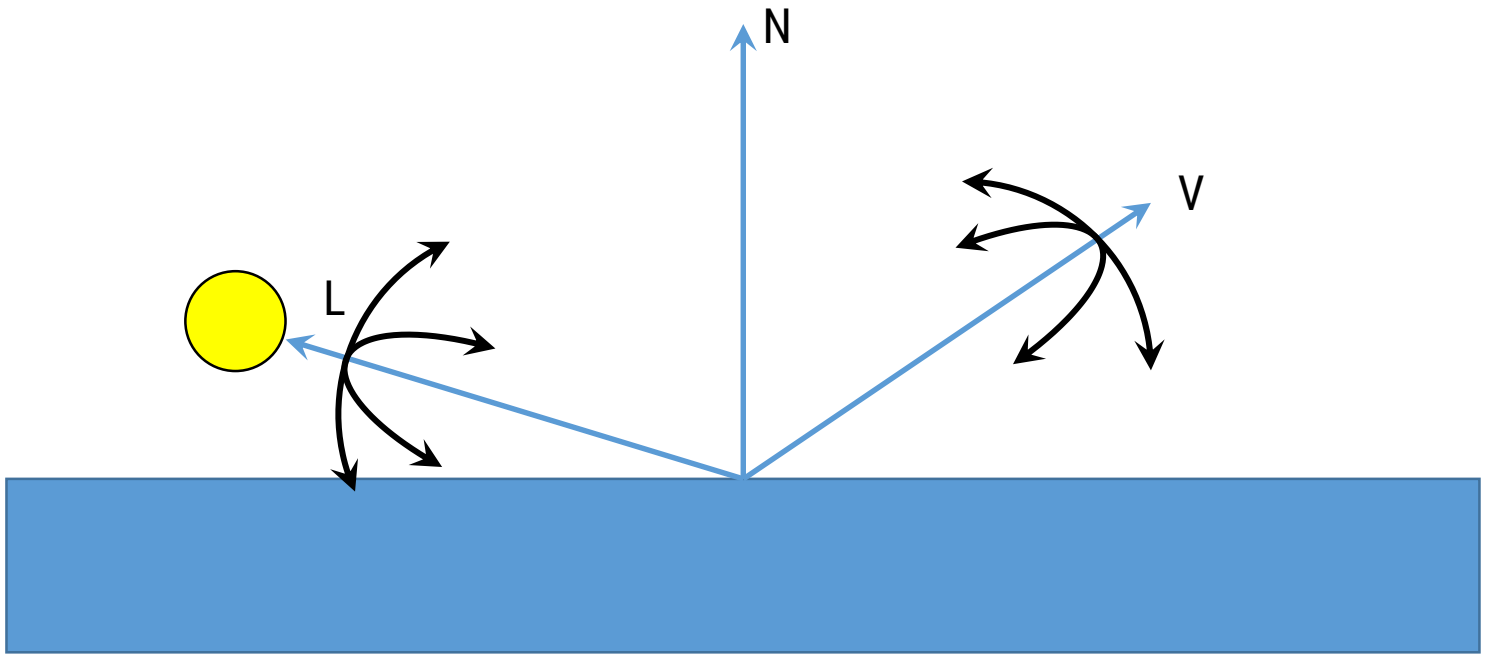
BRDFs

- Bi-directional Reflection Distribution Function
- generic view of the direct reflection behavior at a point

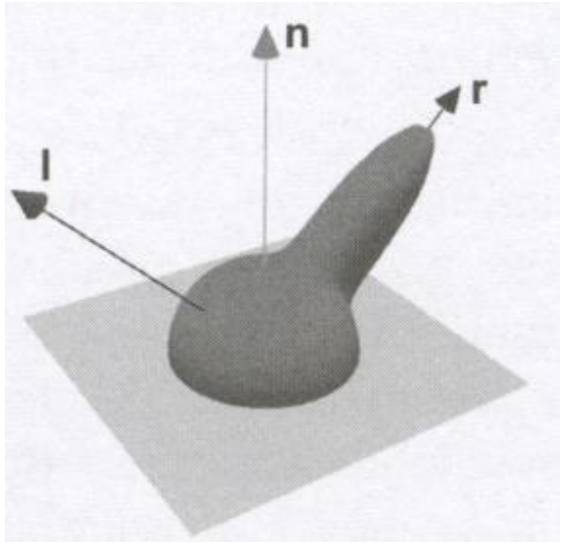


L – vector to light source
N – surface normal vector
R – reflected light ray
V – vector to viewer/observer

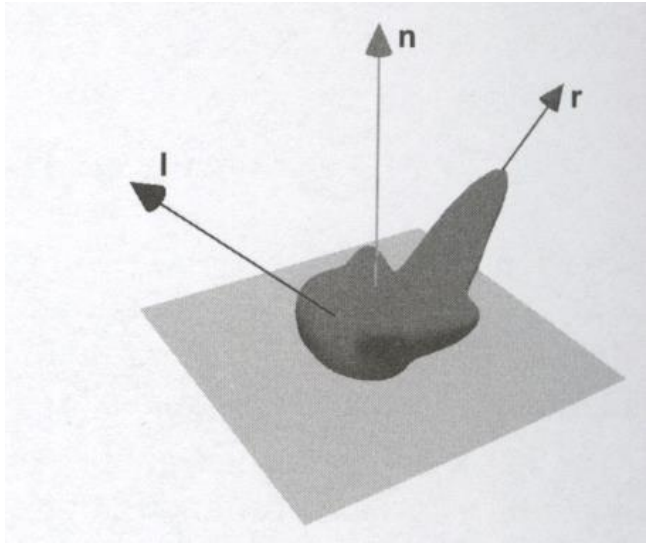
BRDFs

- Bidirectional Reflectance Distribution Function
- generic view of the direct reflection behavior at a point

visualization for one incoming light direction:



Phong



more realistic

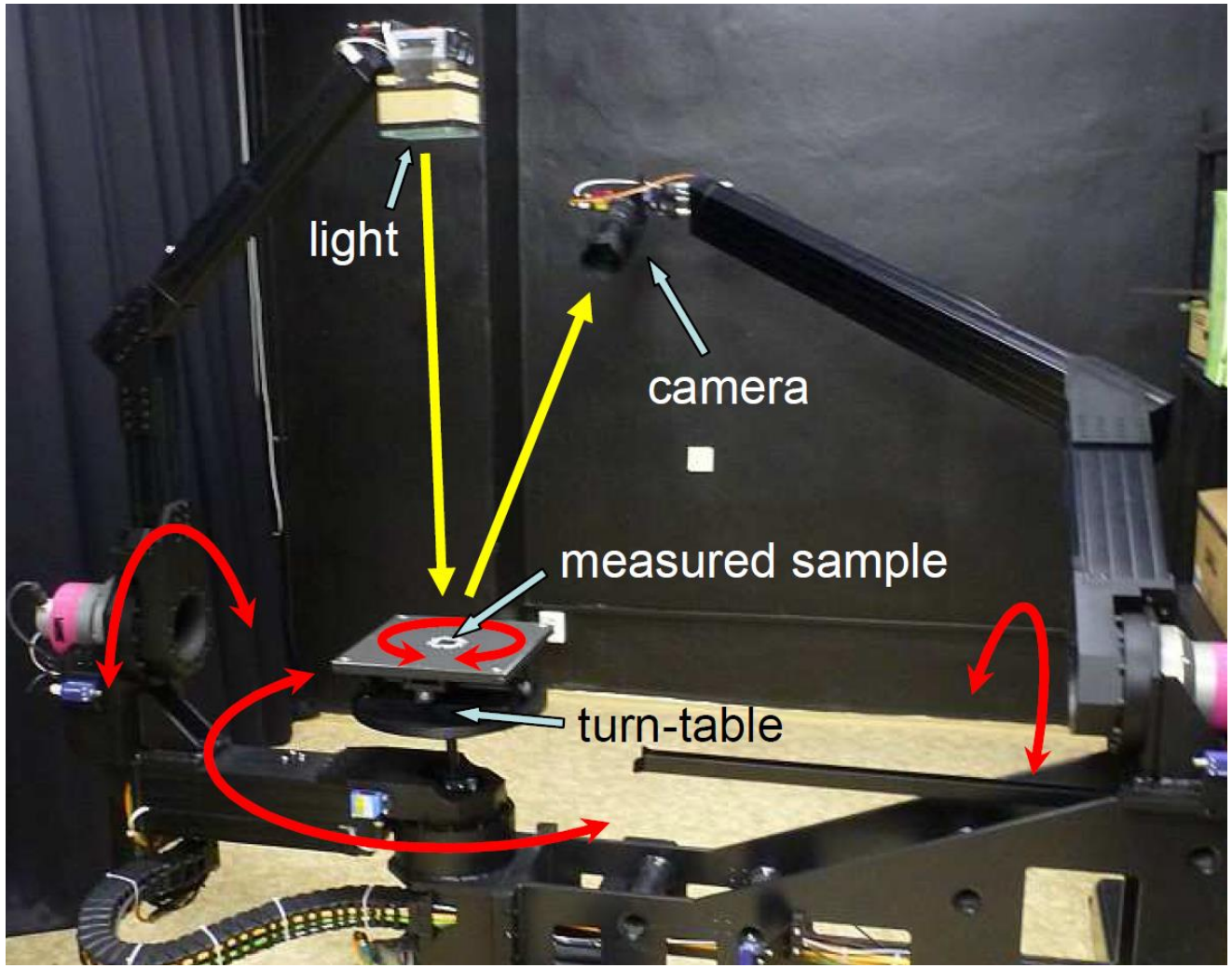
Bender/Brill (2003)

BRDFs

- Bidirectional Reflectance Distribution Function
- generic view of the direct reflection behavior at a point
- can be used as a replacement of diffuse and specular components in illumination computation
- the advanced models typically lead to a BRDF-like formulation
- dependence of reflection on light frequency needs to be considered on top of directional components

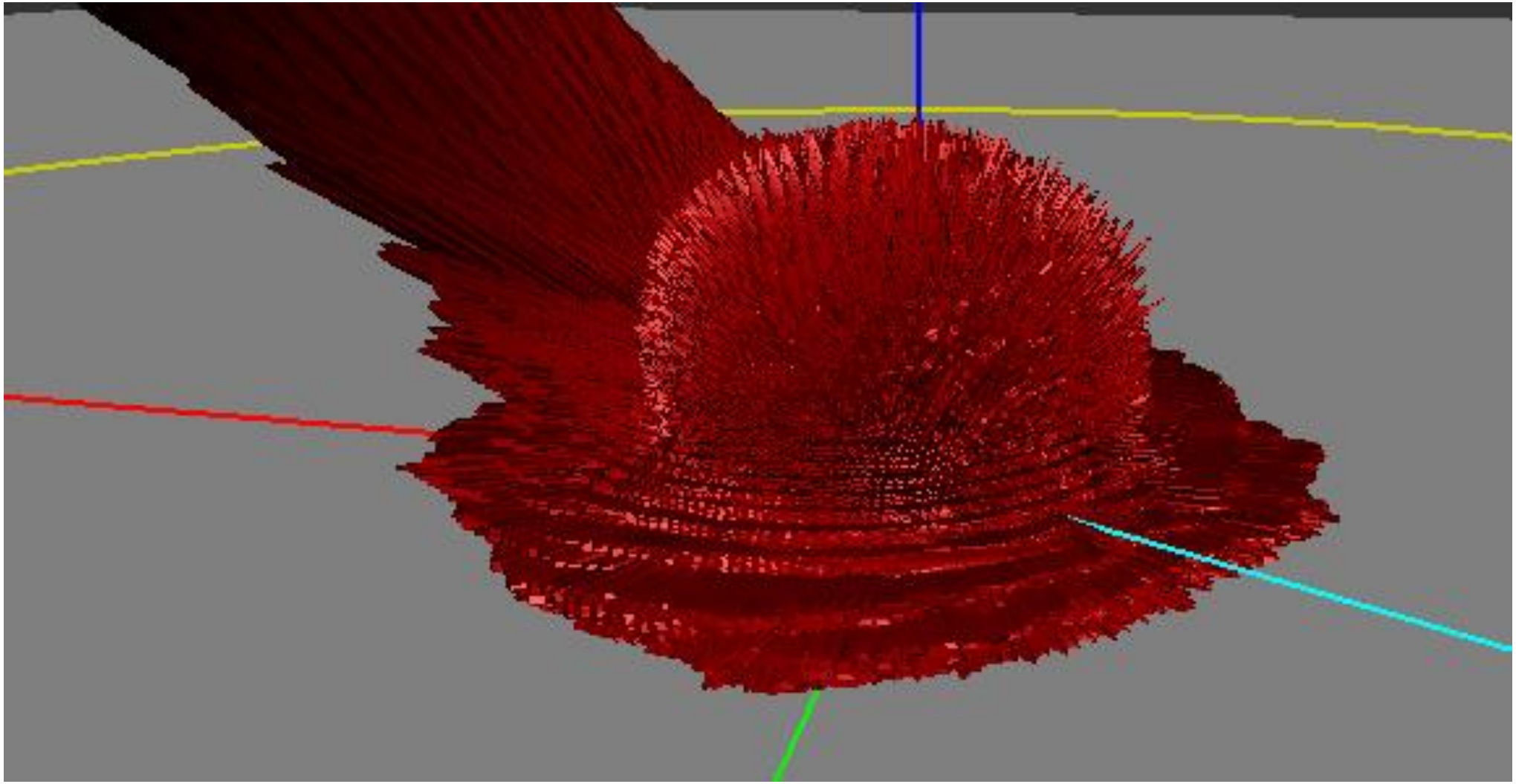
Measuring the BRDF

- bi-directional camera movement
- bi-directional light source movement
- combination of many measurements to final BRDF



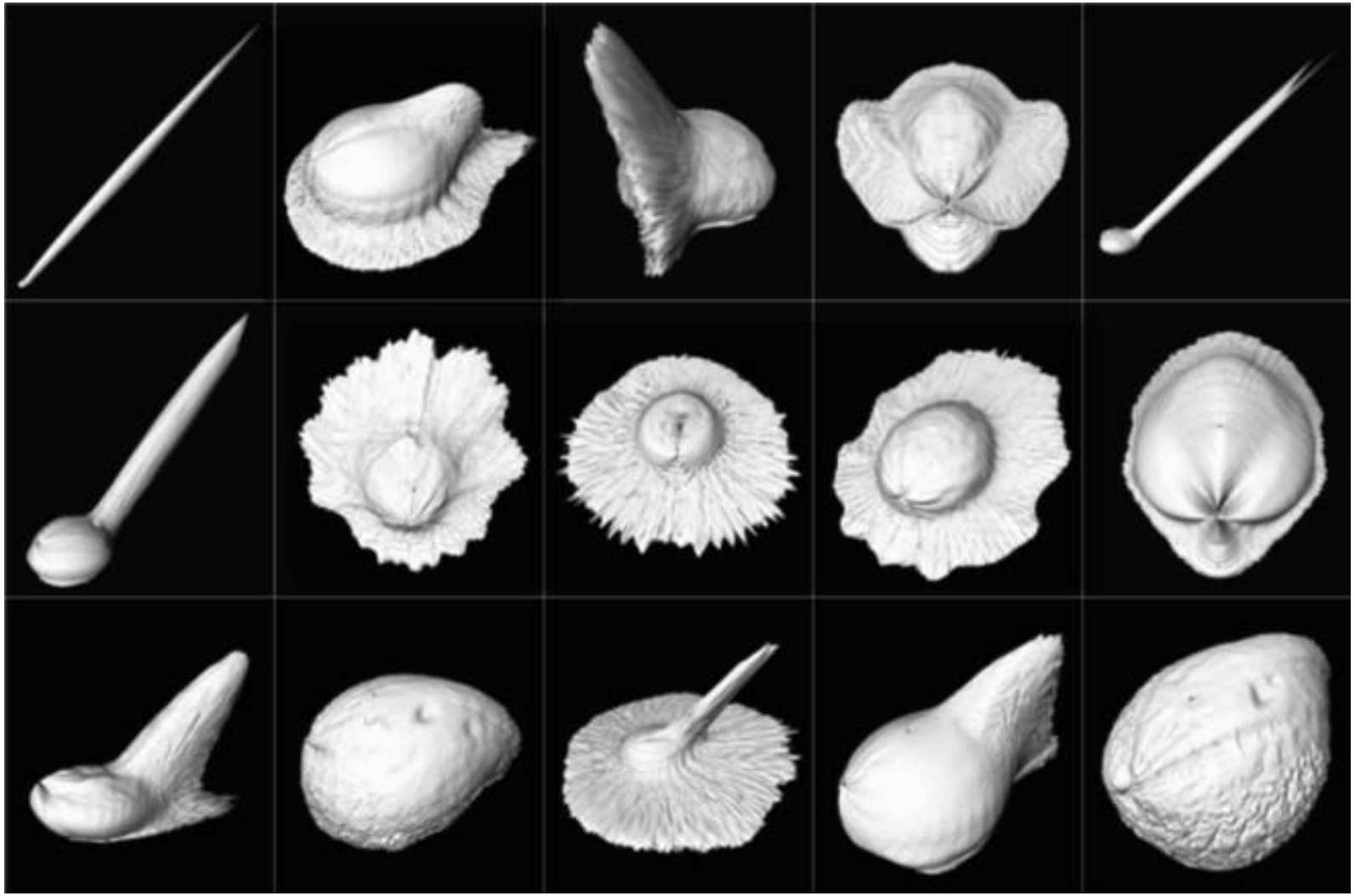
[Filip et al., 2013]

Measuring the BRDF



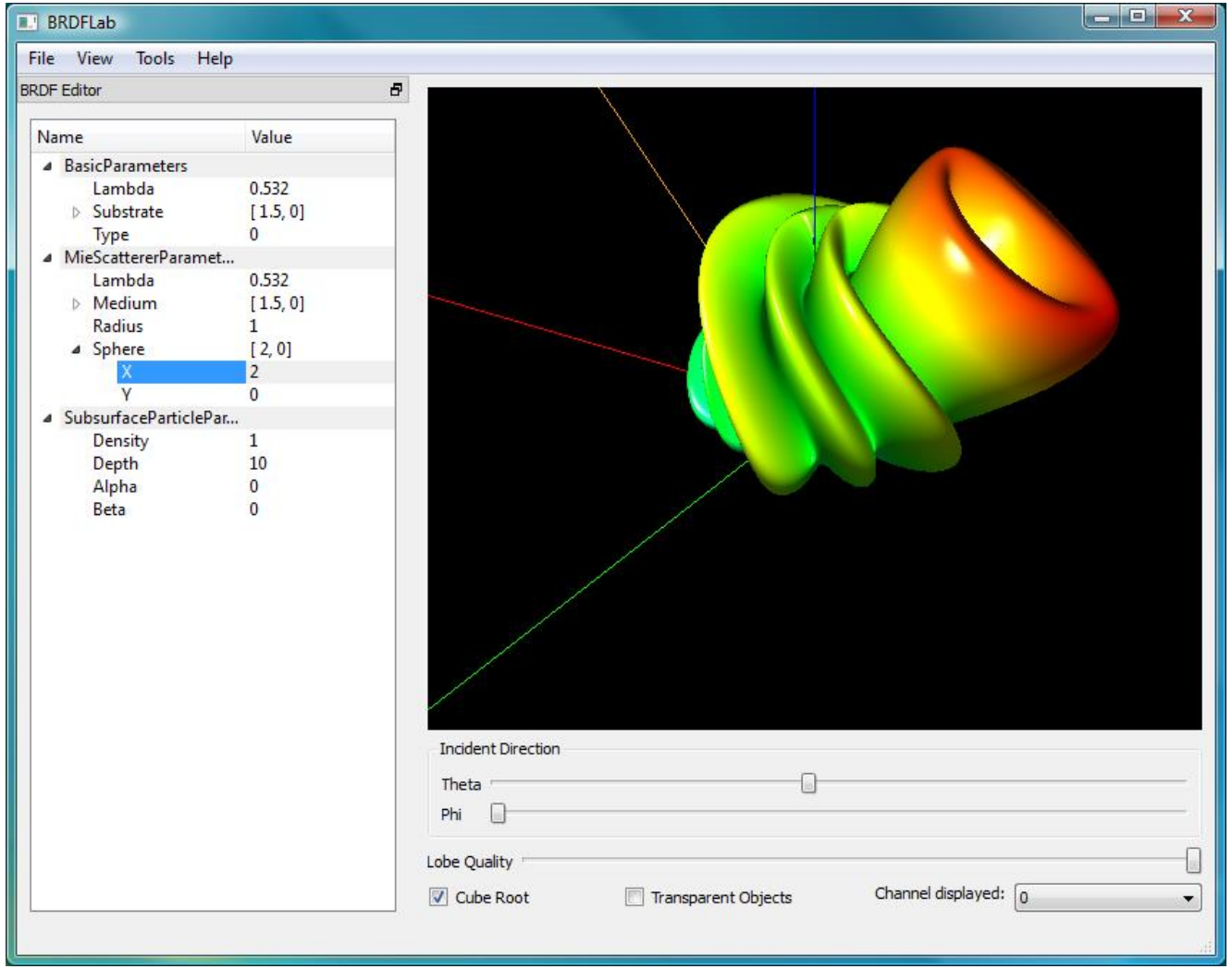
BRDF of nylon

Measuring the BRDF



[Park & Lee, 2015]

Simulating the BRDF

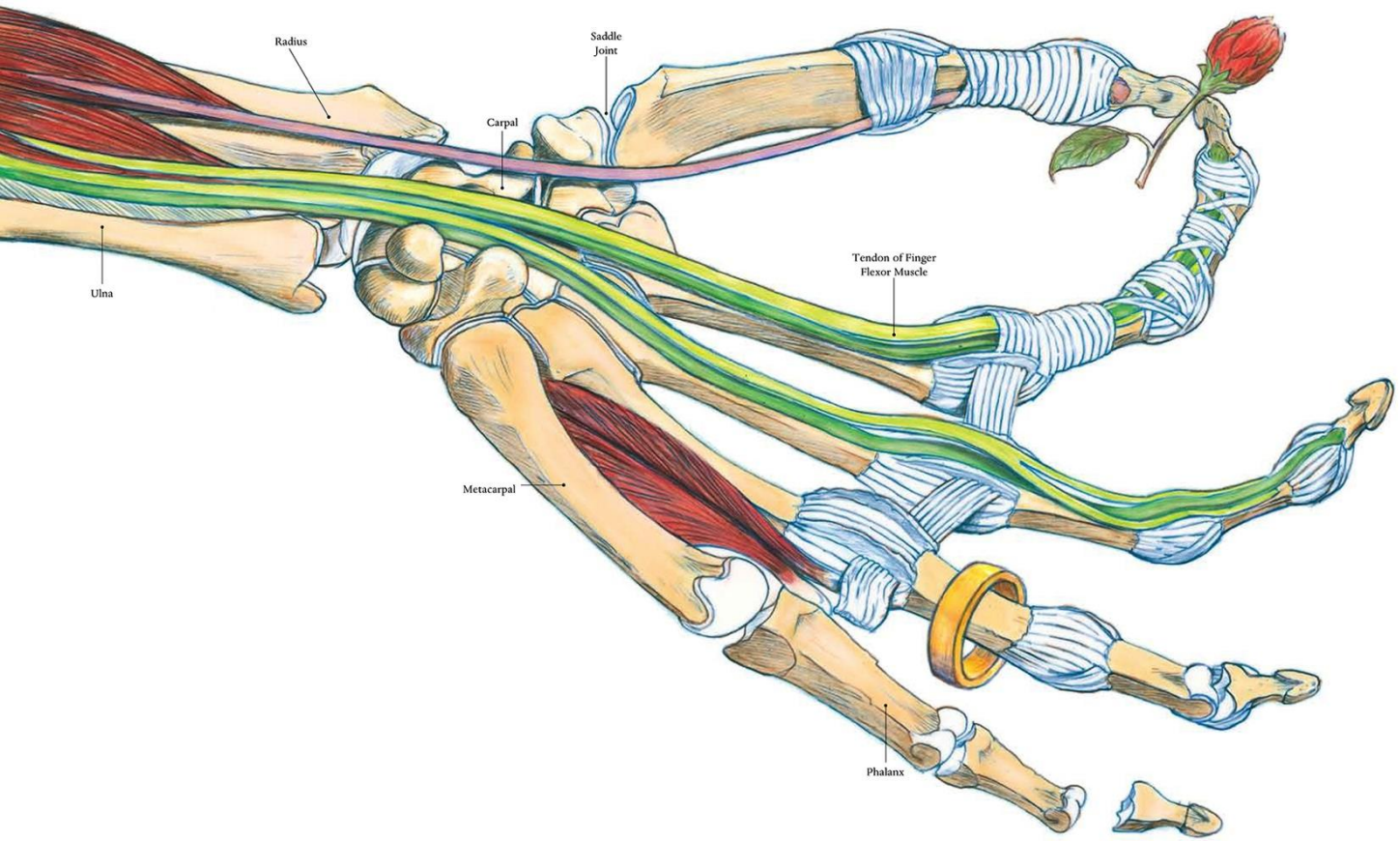


http://brdflab.sourceforge.net/

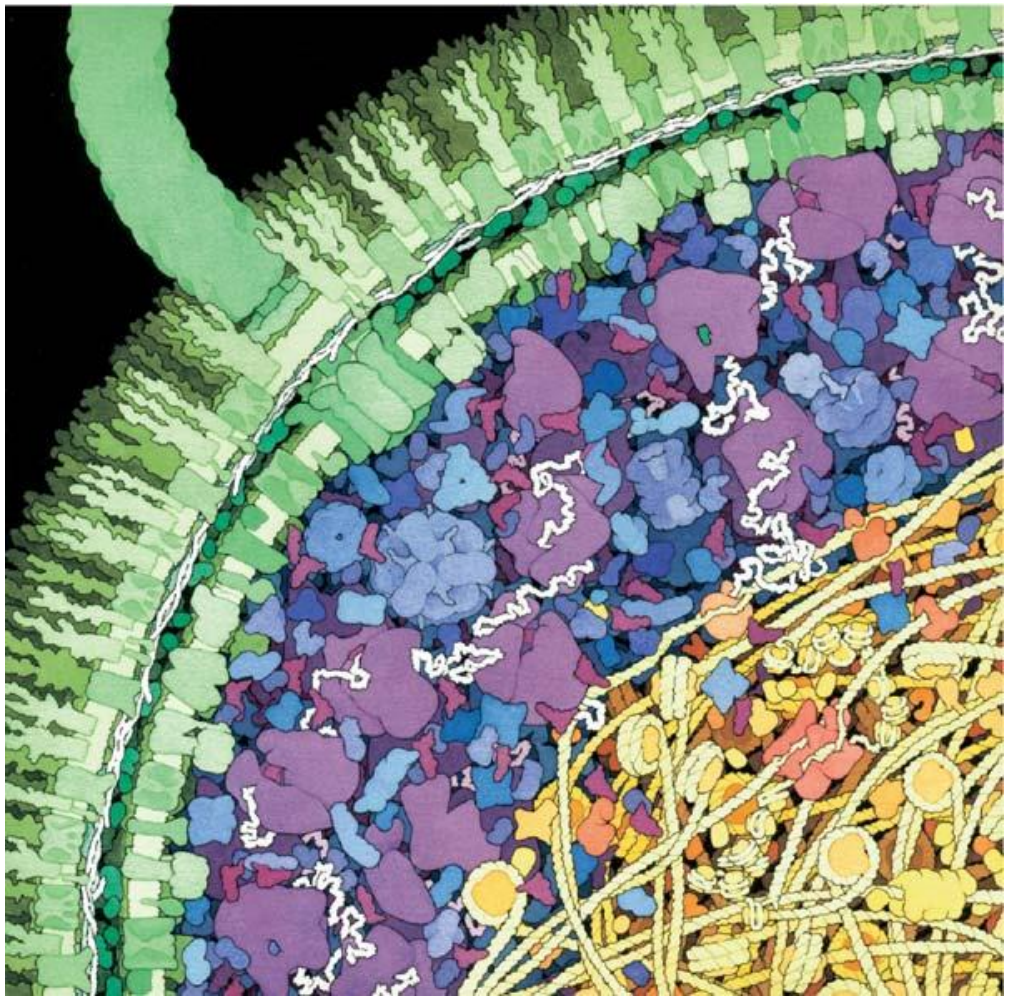
Status so far: “Photorealism”

(global illumination)

Other forms of depiction …



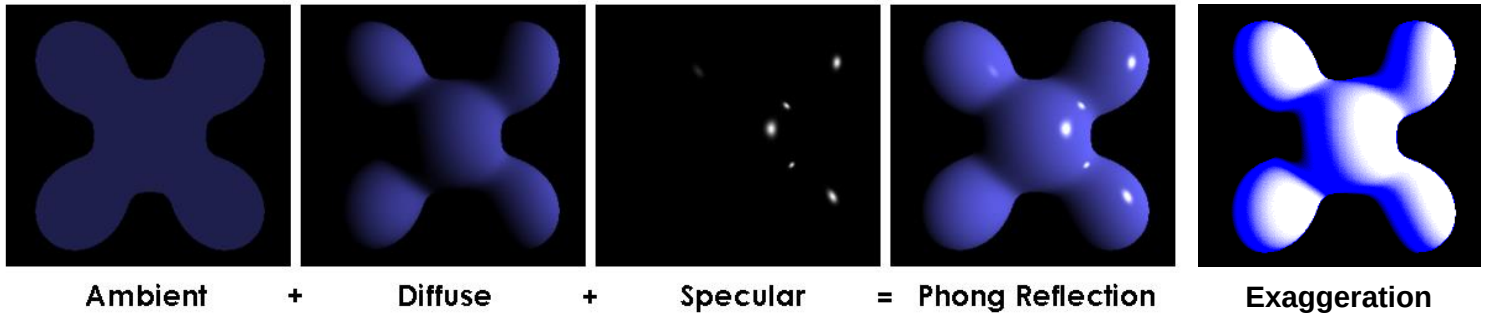
David Macaulay, “The Way We Work”

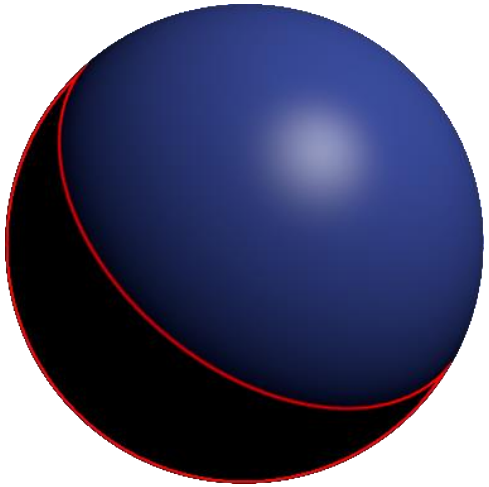


Goodsell, 2005

Gooch Model

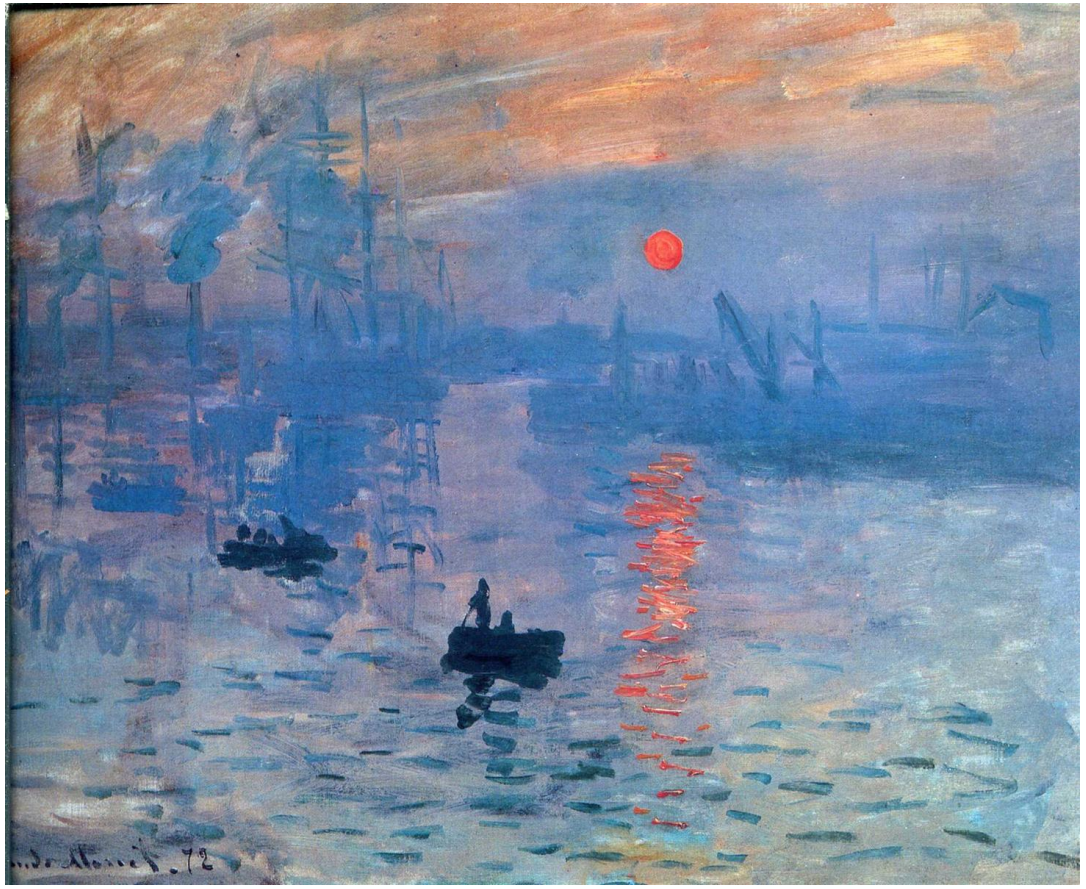
- limitations of past models:
  - areas with only ambient illumination appear flat





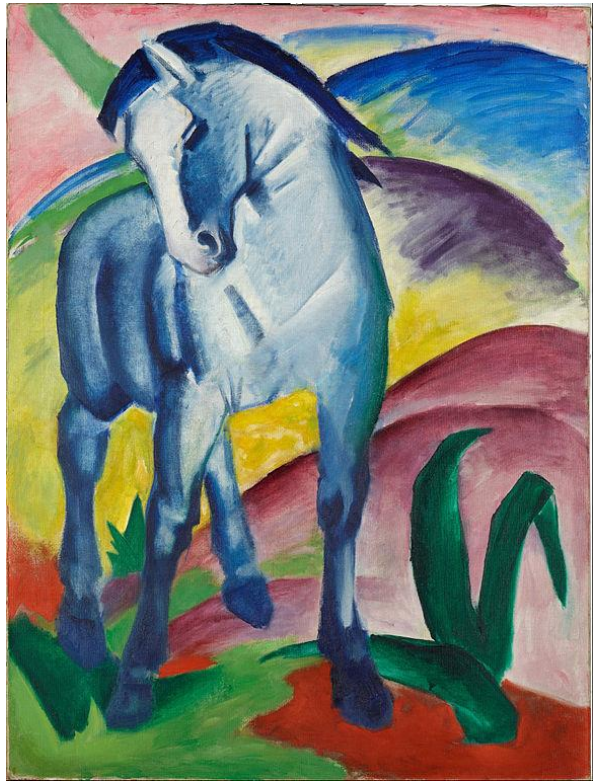
- goal:
  - inspiration from traditional illustration and painting
  - cool to warm color transitions
  - produce images for (technical) illustrations

Visual Inspirations



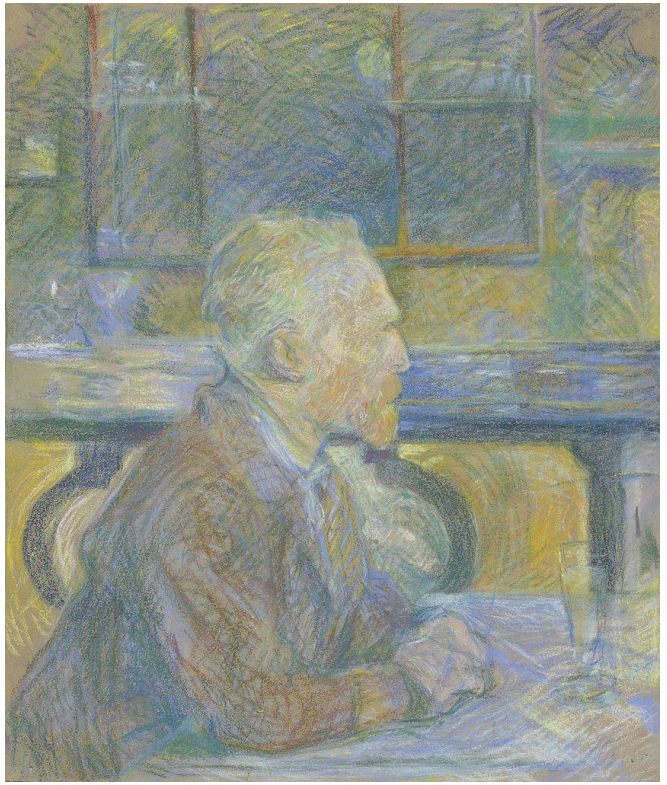
Claude Monet (1872): Sunrise

Visual Inspirations



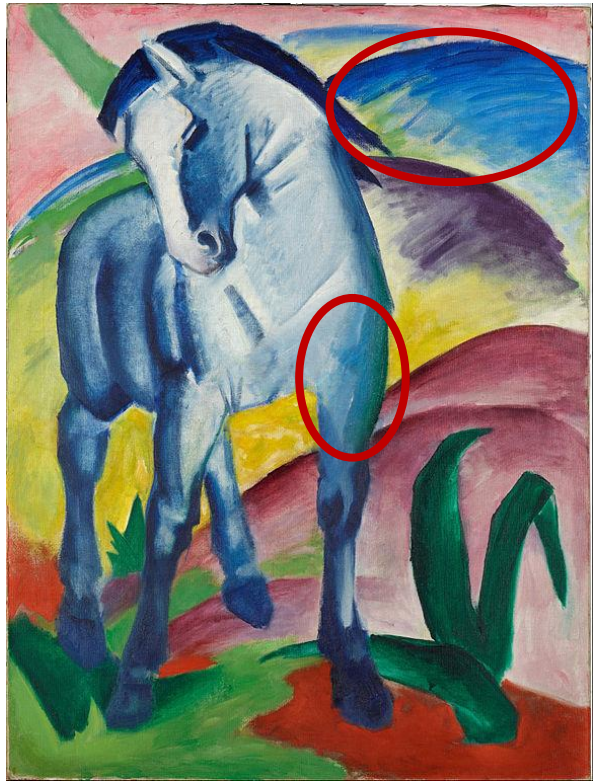
Franz Marc (1911):
Blaues Pferd I

Vassily Kandinsky (1908):
Murnau, Dorfstrasse



Henri de Toulouse-Lautrec (1887):
Vincent van Gogh

Visual Inspirations



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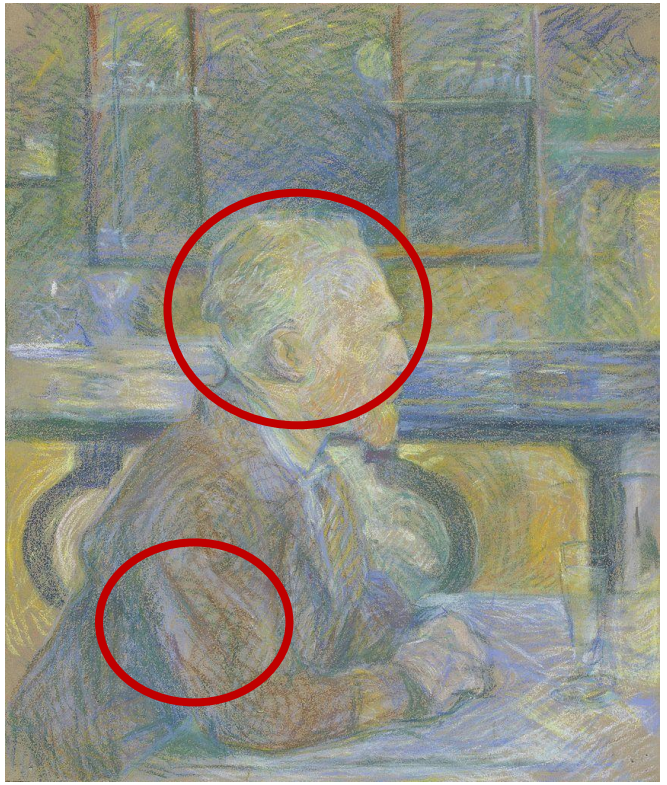


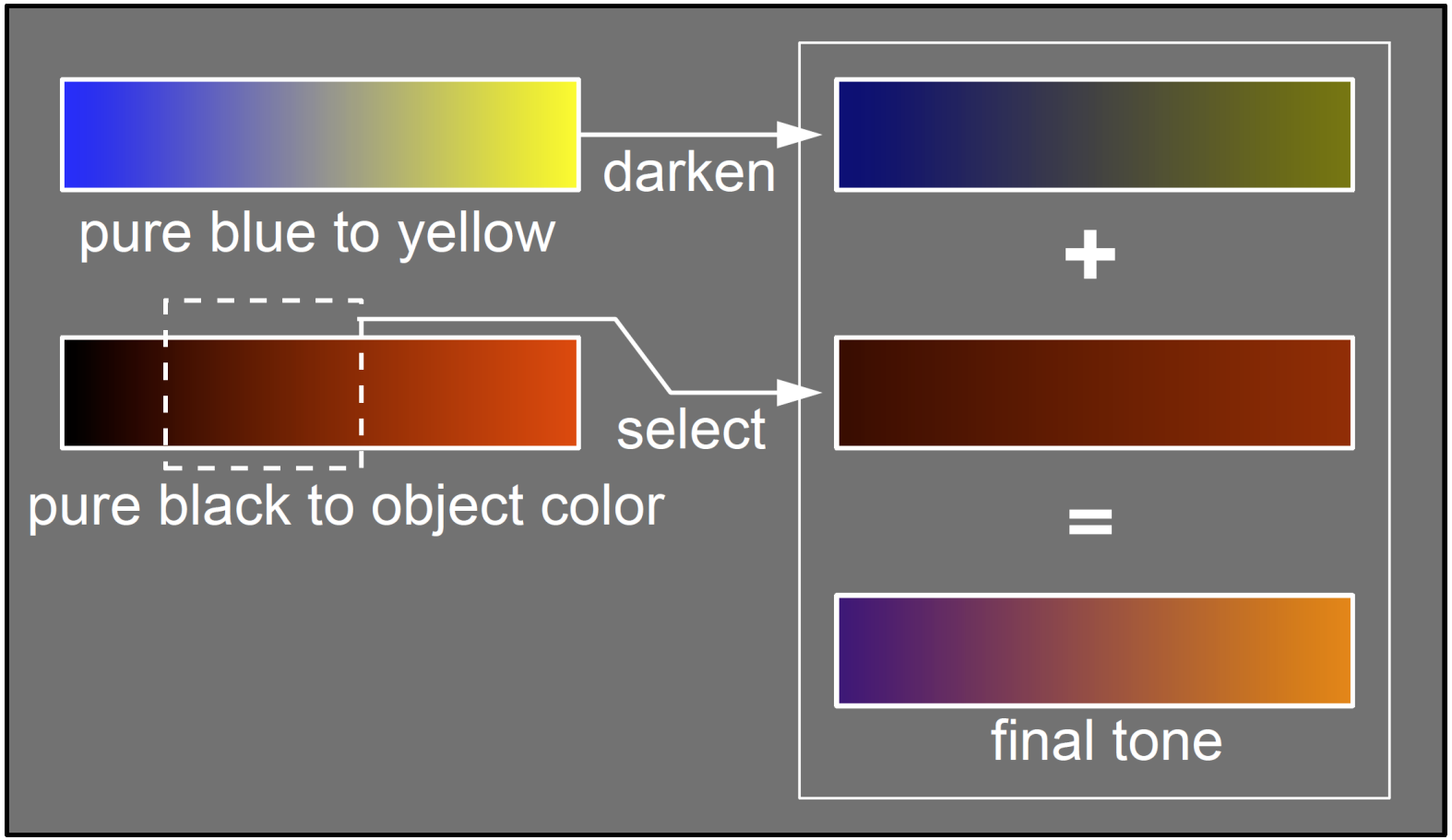
Henri de Toulouse-Lautrec (1887):
Vincent van Gogh

Gooch Model: Principle of Color Mixing

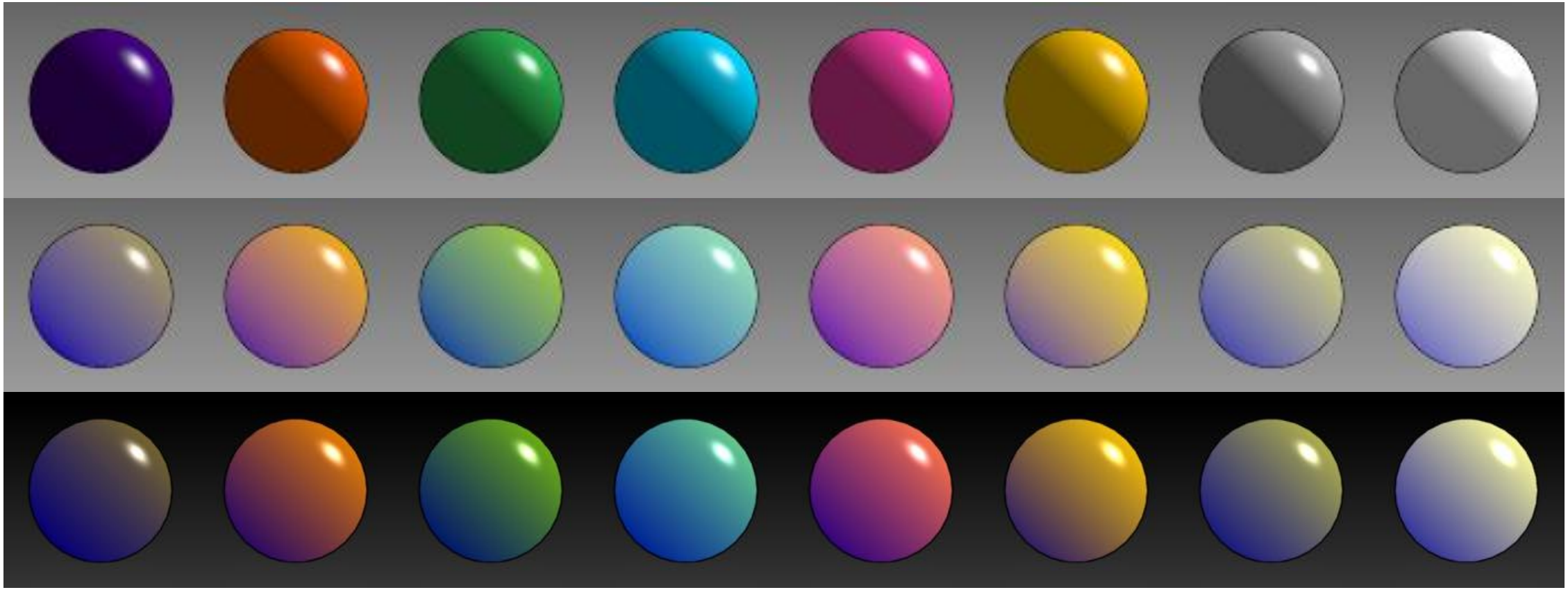
$$I_d = \left(\frac{1 + L \cdot N}{2}\right) k_{cool} + \left(1 - \frac{1 + L \cdot N}{2}\right) k_{warm}$$

$$k_{cool} = k_{blue} + \alpha k_d$$

$$k_{warm} = k_{blue} + \beta k_d$$

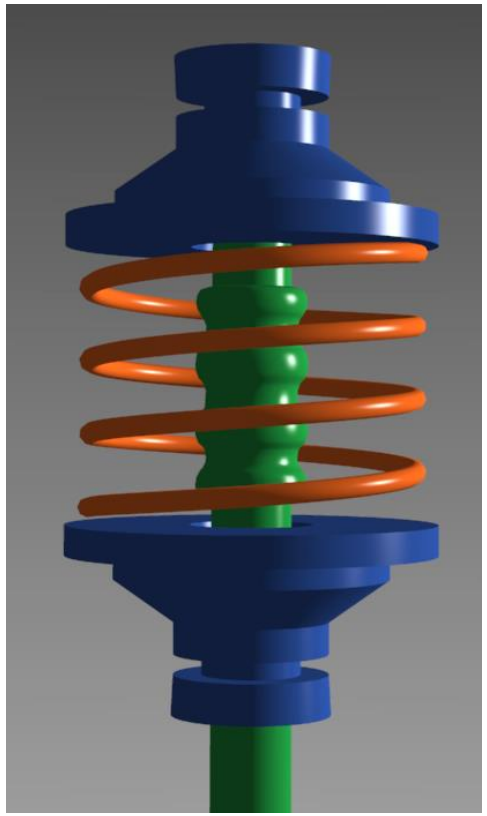


Gooch Model: Results

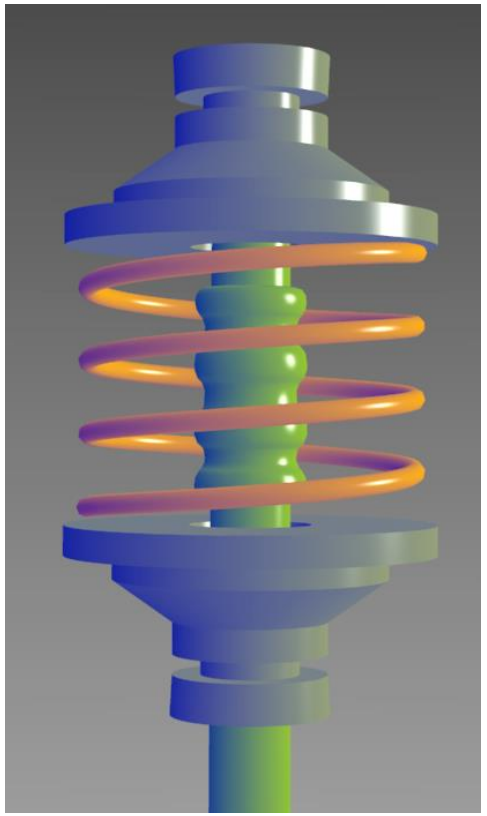


- notice the lack of hard border between diffuse and ambient illumination in the Gooch-illuminated versions on the bottom

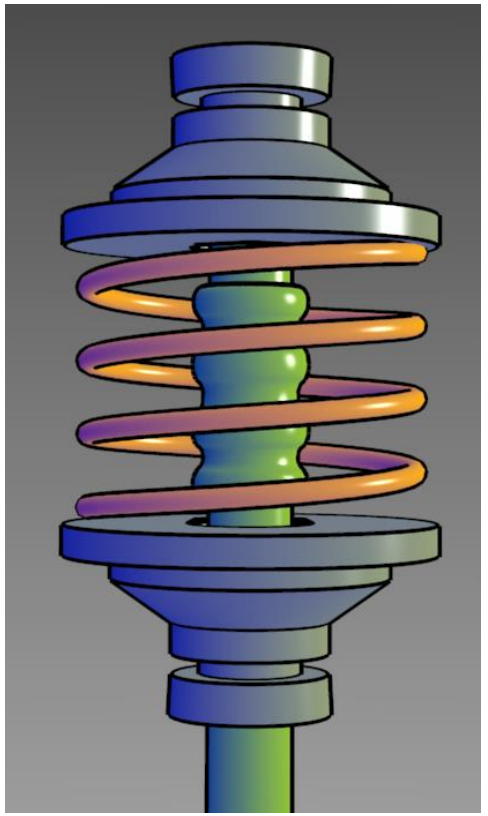
Gooch Model: Results



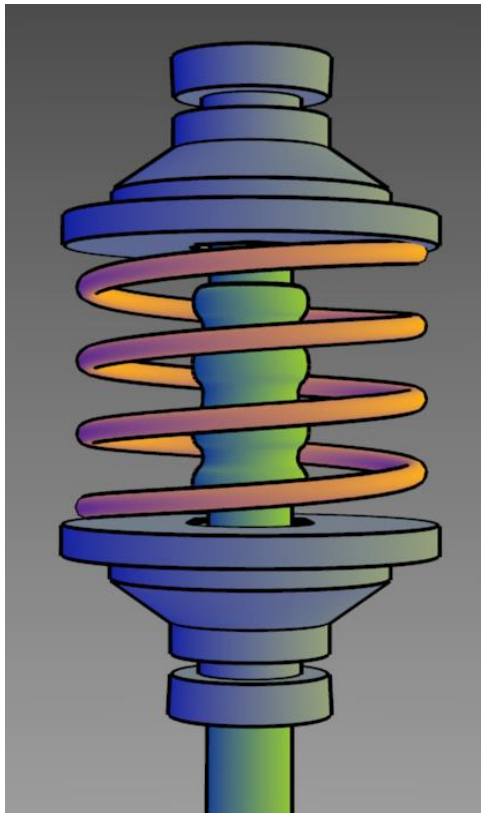
Phong



Gooch model



Gooch model
plus lines



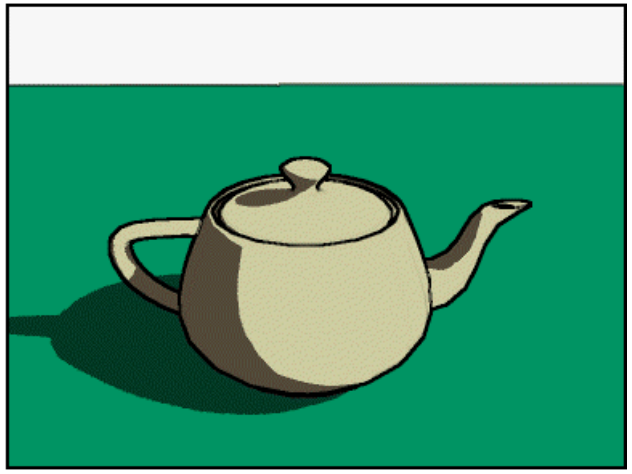
simulation using Phong
based on 2 colored lights

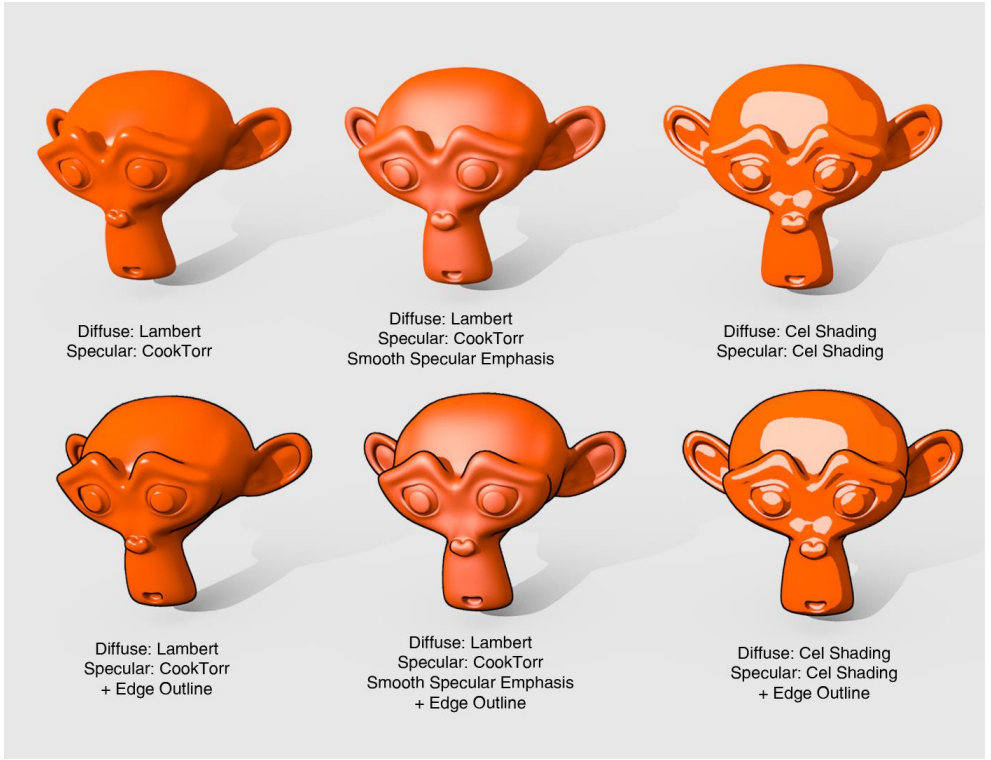
Other Extreme: Cartoon/Cel “Shading”

- inspired by traditional cel animation

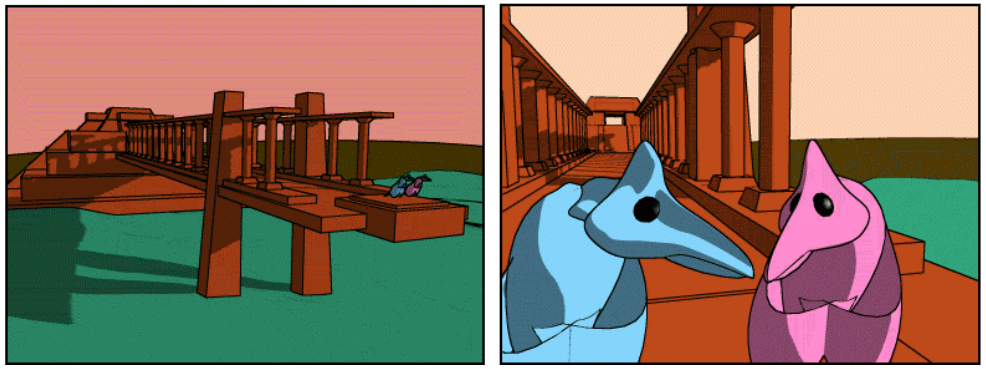
Other Extreme: Cartoon/Cel “Shading”

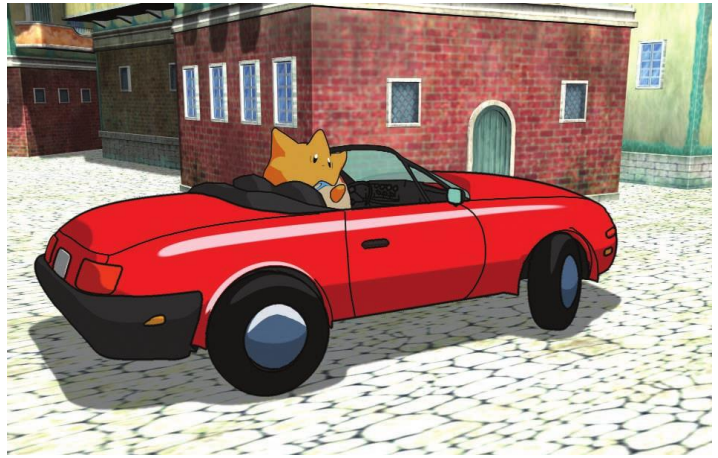
- core idea: reduce the continuous reflectance to discrete steps

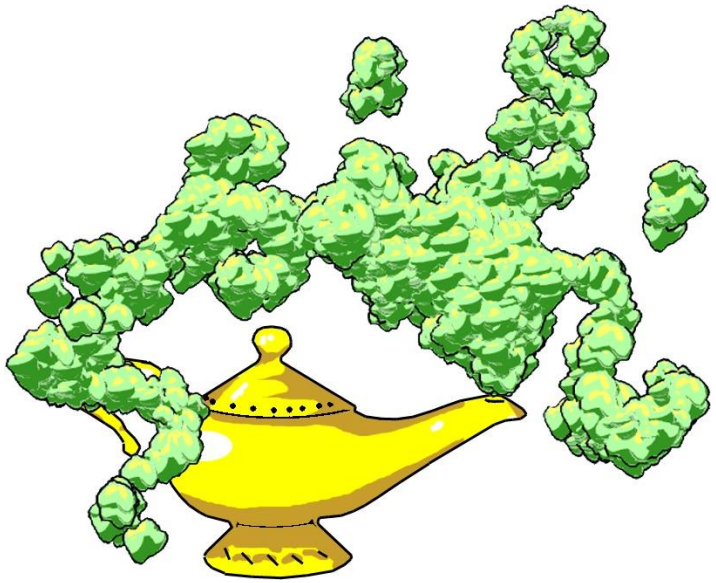




Other Extreme: Cartoon/Cel “Shading”







Advanced Illumination Models: Summary

- based on physical reflection of light on surfaces
- wide range of heuristics with
  - varying degrees of realism (both visual and physical foundations)
  - varying complexities (also computational complexities)
  - goal is generally “photo-realism”
  - can be captured/measured in BRDF
- other models inspired by illustration and artworks
- selection based on visual goals, available data, and computational power