Computer Graphics (CS 563)
Lecture 3: Advanced Computer Graphics

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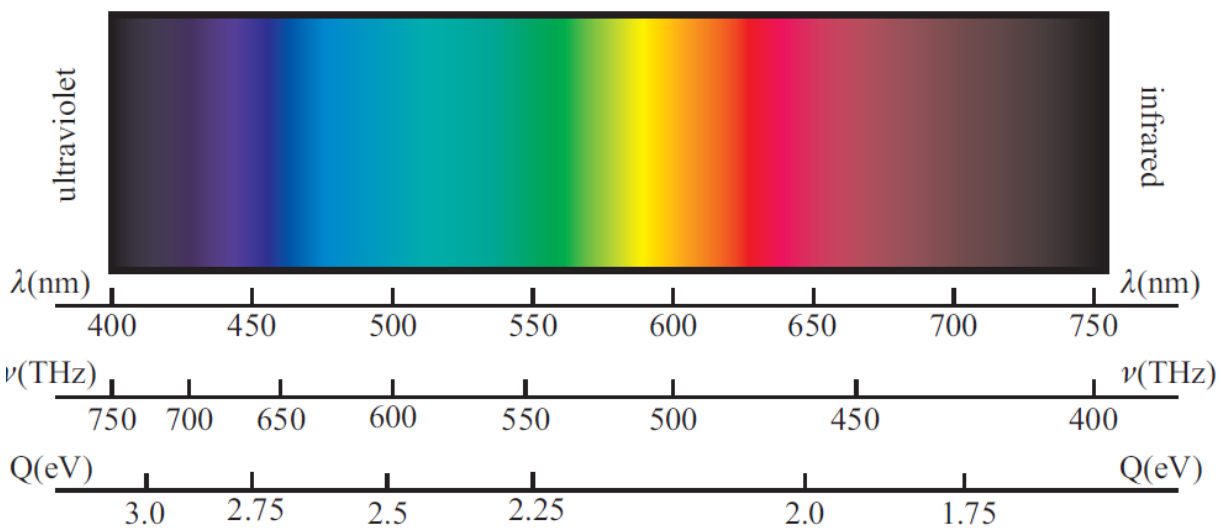
Advanced Shading

- Radiometry: field concerned with transmission of light
- Photometry: concerned with *how humans see* transmission of light
- Visible spectrum: Wavelengths human eye can see
  - Ranges from about 400 - 750nm



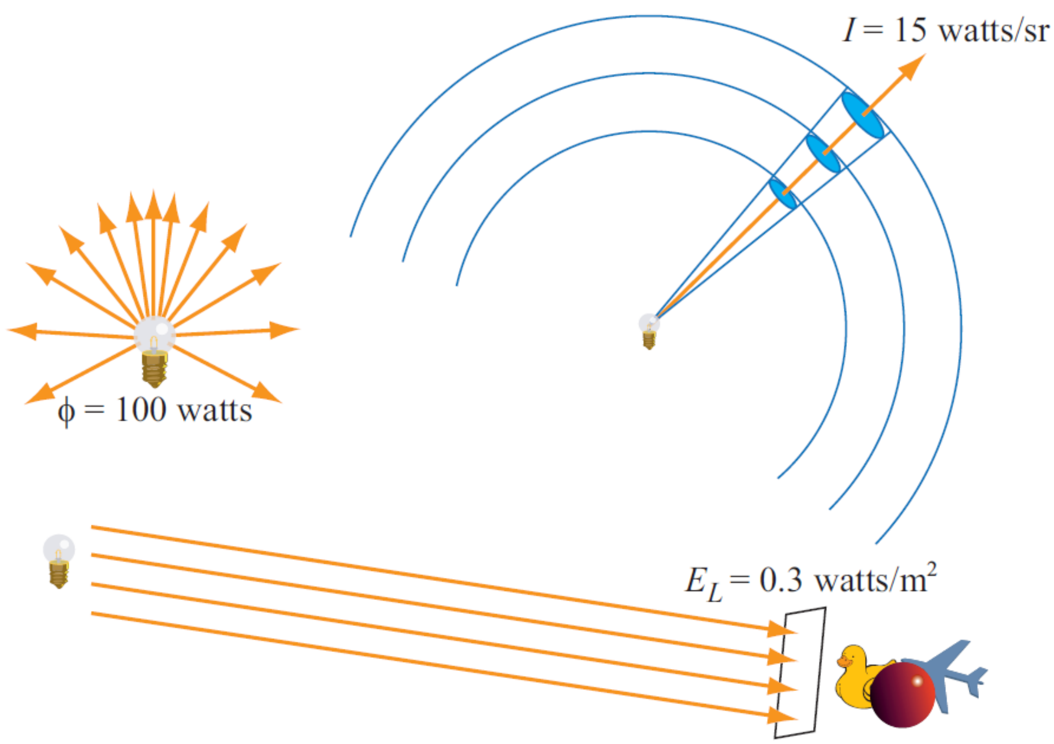
Radiometric & Photometric Quantities

- **Radiant Energy, Q (Joules):** Radiant energy of photons in a light source
- **Radiant Flux (Watt) or power, dQ/dt:** Joules emitted per second
- **Irradiance: dQ/dA:** Joules per unit area

Radiometric Quantity: Units	Photometric Quantity: Units
radiant energy: joule (J)	luminous energy: talbot
radiant flux: watt (W)	luminous flux: lumen (lm)
irradiance: W/m^2	illuminance: lux (lx)
radiant intensity: W/sr	luminous intensity: candela (cd)
radiance: W/m^2-sr	luminance: cd/m^2 = nit

Irradiance

- **Irradiance** measures light flowing **into** a surface
- **Exitance** measures light flowing **out of** a surface
- **Solid angle:** set of angles in 3D, measured in steradians (sr)



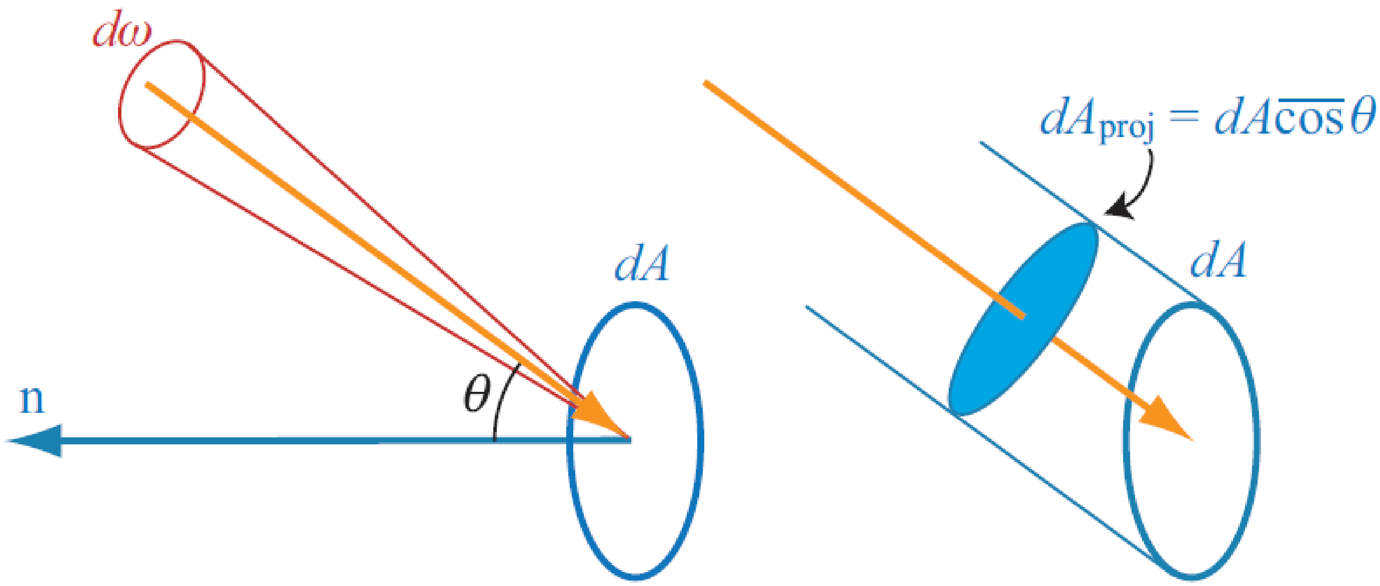
Radiance

- Radiance, *L:*
  - what sensors, eyes cameras see
  - Measures illumination in single ray of light
  - Defined as flux density with respect to both area and solid angle

$$L = \frac{d^2\Phi}{dA_{proj}\,d\omega}$$

  - Where dA_{proj} refers to dA projected to the plane perpendicular to the ray

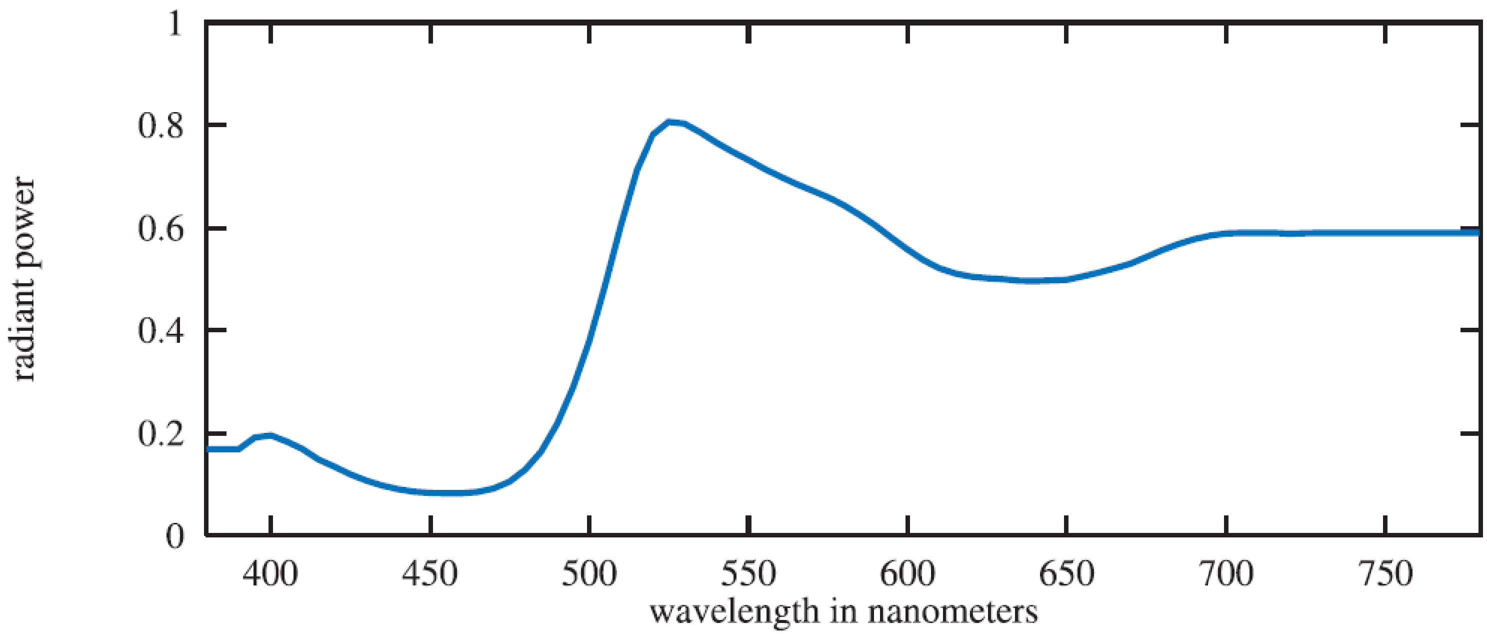
Unit Projected Area



$$dA_{proj} = dAcos\Theta$$

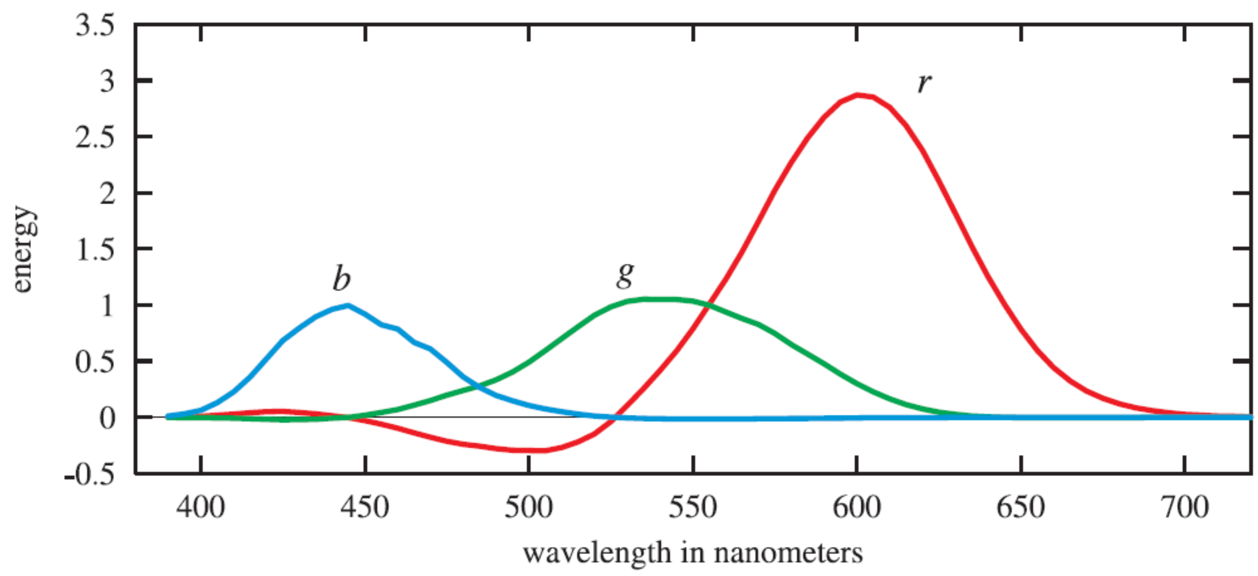
Colorimetry

- Humans can distinguish about 10 million colors
- Human eye sees wavelengths between 380-700nm
- Different surfaces reflect/suppress different wavelengths



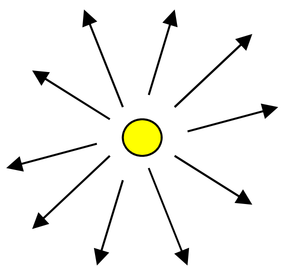
Colorimetry

- Light going into eye detected by retina in the eye
- Retina has 3 types of receptors => Color represented typically by 3 numbers (CIE, RGB, etc)
- Representations can be converted. E.g. RGB to CIE

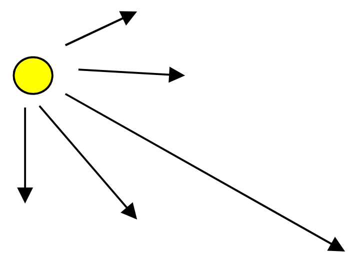


Light Sources

- Abstractions that are easier to model

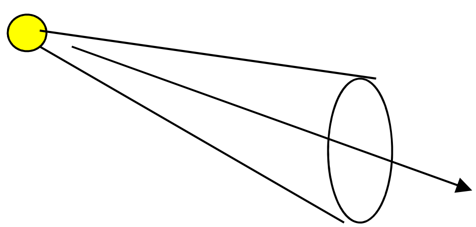


Point light

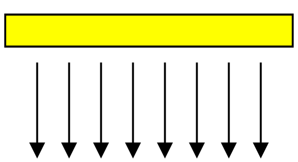


Directional light

Light intensity can be independent or dependent of the distance between object and the light source



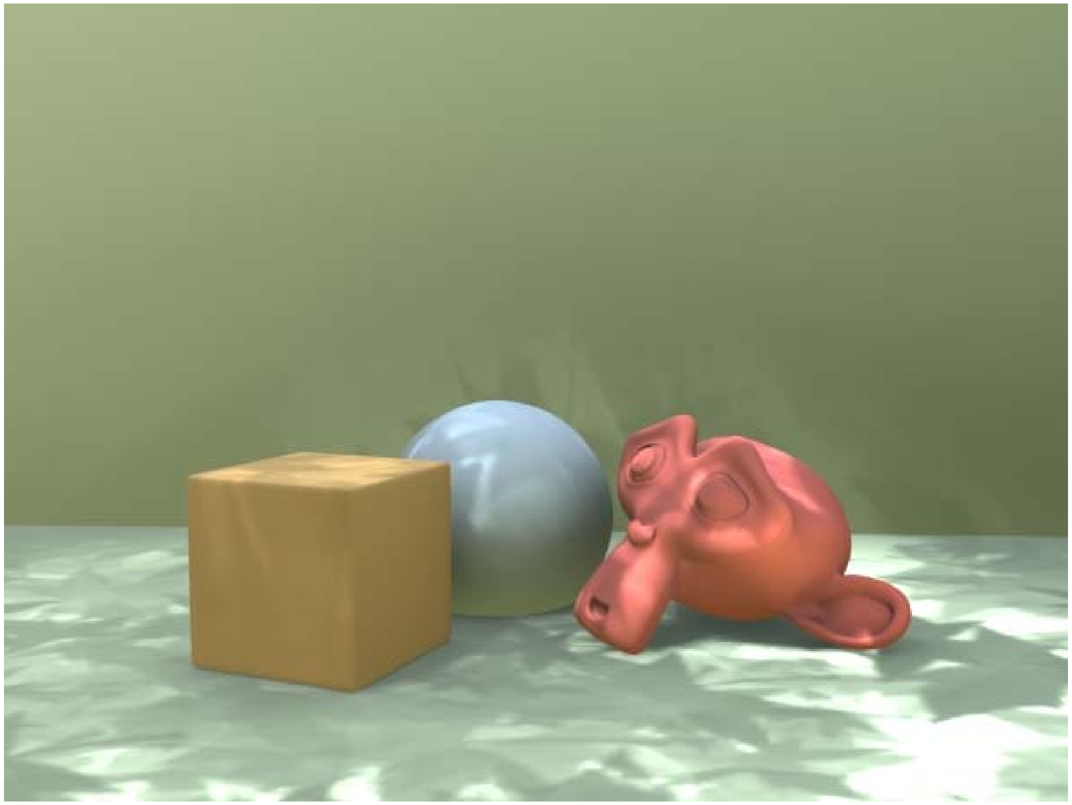
Spot light



Area light

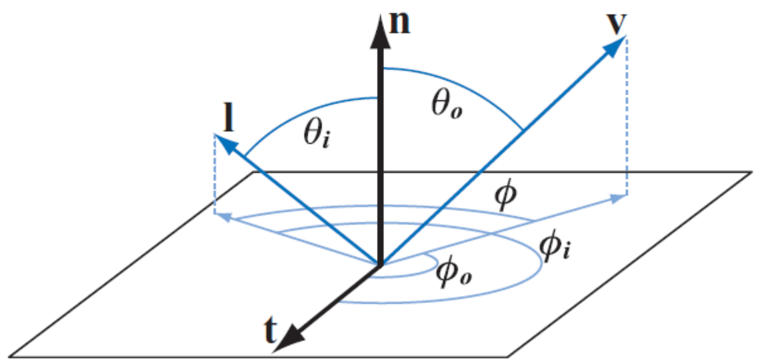
Textured Lights

- Use a texture to modulate light intensity
- Below: light modulated by leaf texture pattern

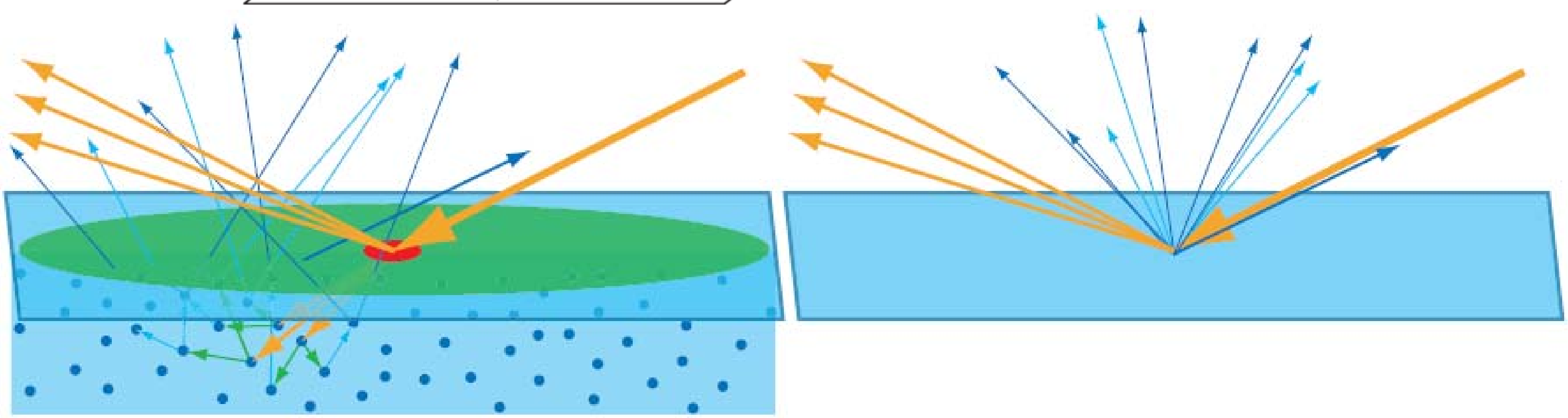


BRDF Theory

- BRDF: Bidirectional Reflectance Distribution Function
- Expresses energy reflected in outgoing direction given incoming direction



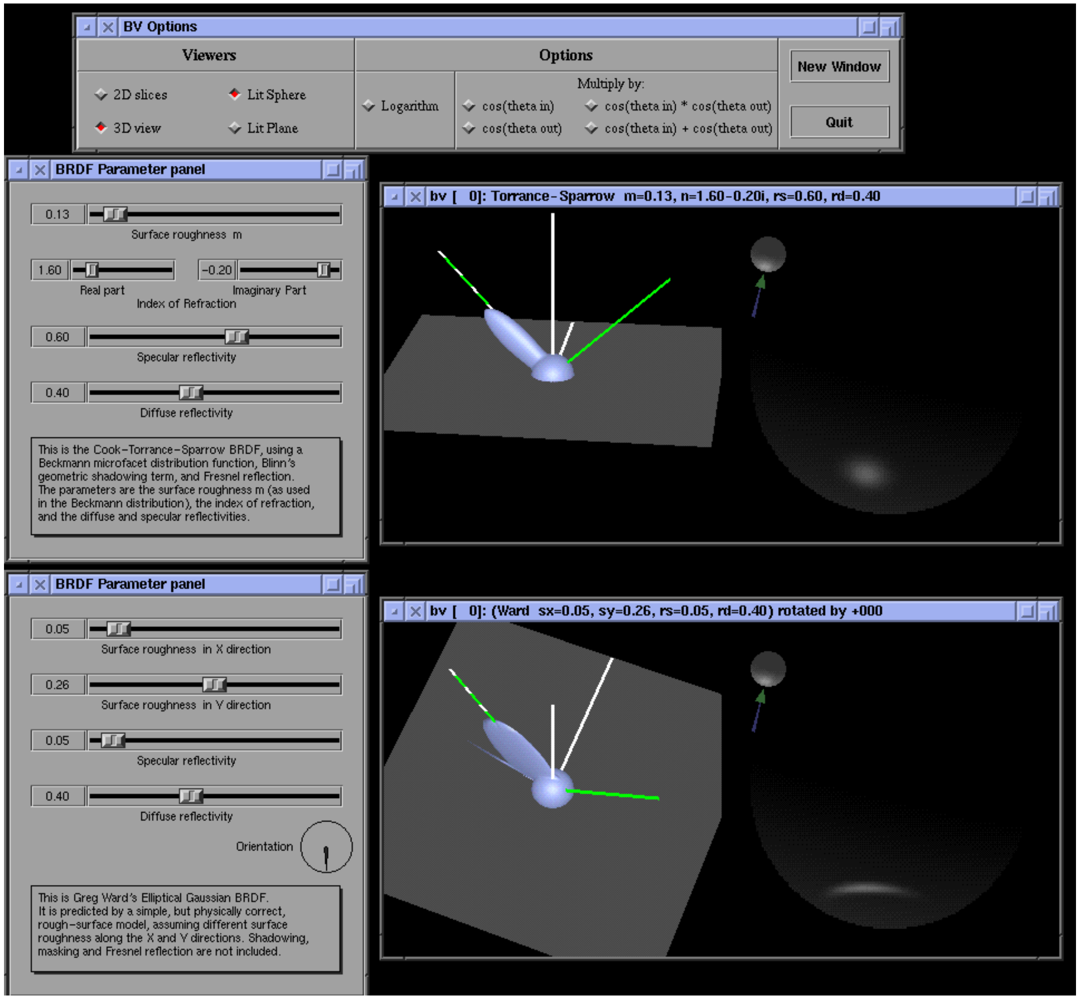
$$f(\mathbf{l}, \mathbf{v}) = \frac{dLo(\mathbf{v})}{dE(\mathbf{l})}$$



Subsurface scattering (BSSRDF) Surface reflection (BRDF)

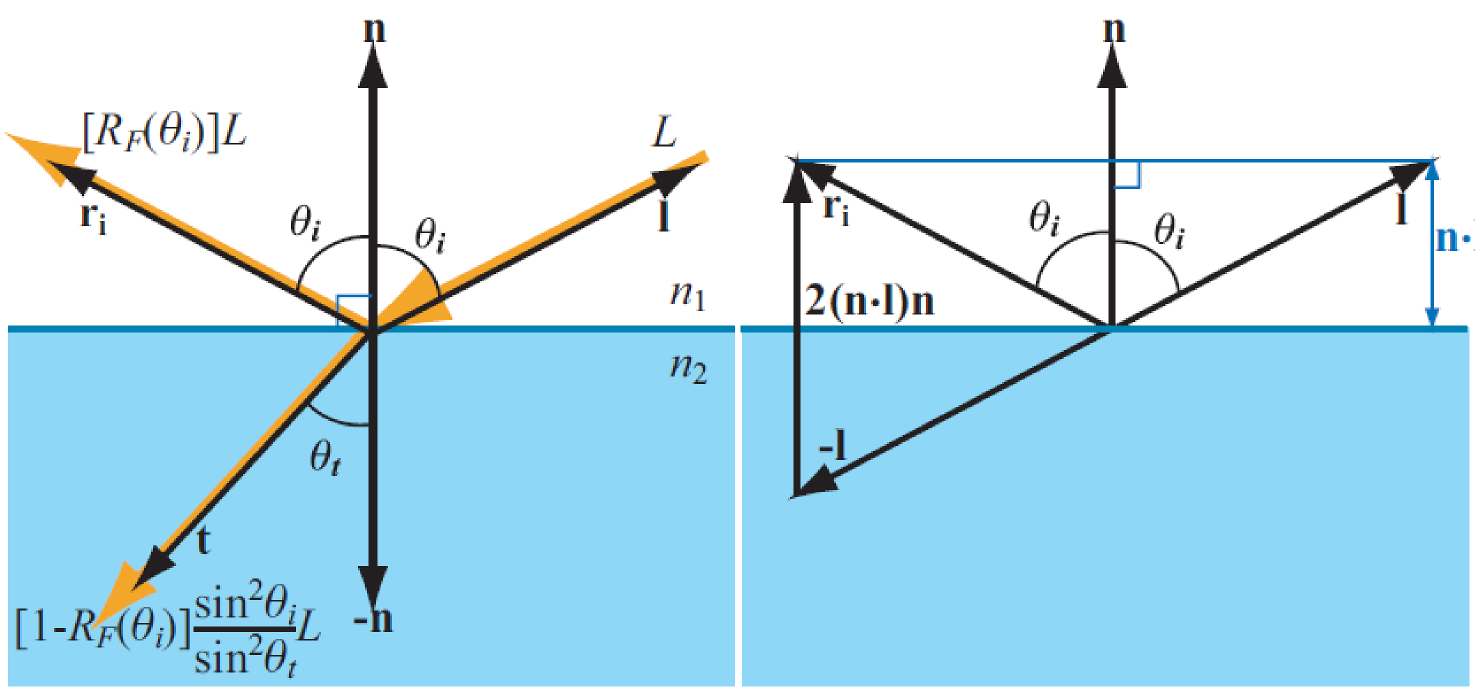
Visualizing BRDFs

- Visualize output in any direction for given incoming angle



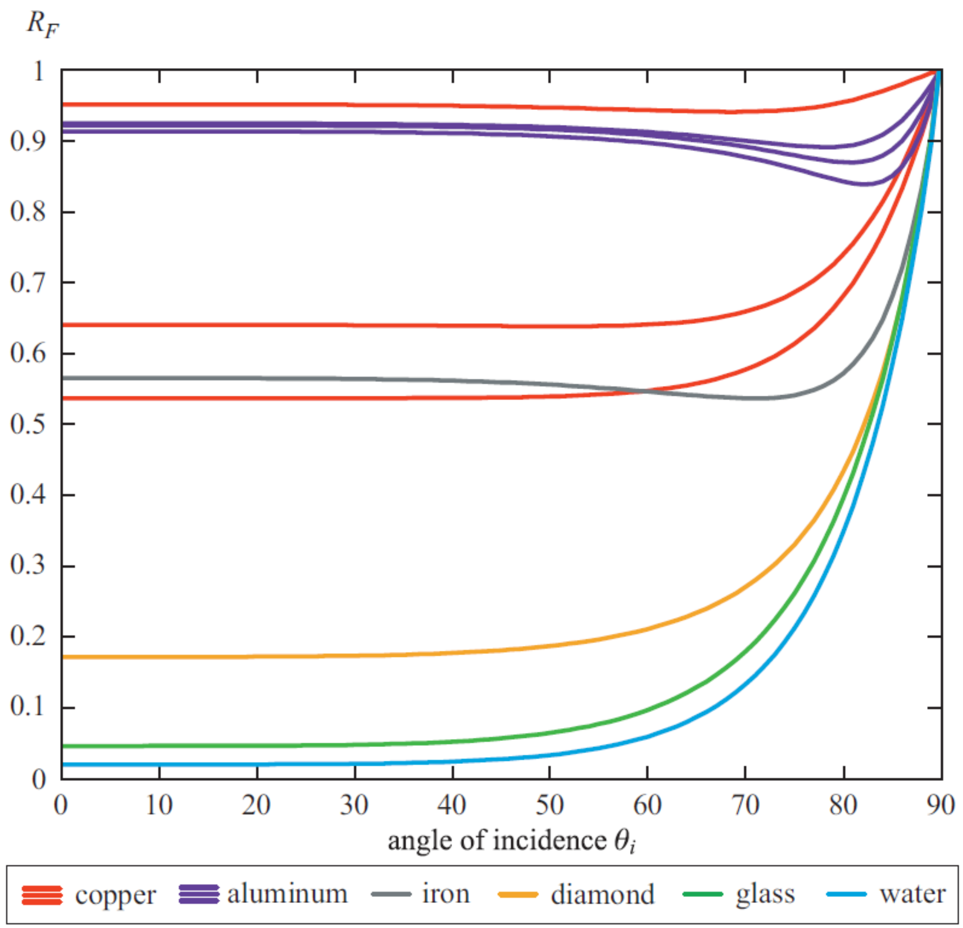
Fresnel Reflectance

- Equation that determines what fraction of incident light is reflected (and what fraction is transmitted)



Fresnel Reflectance

- Depends on angle of incidence and material



Fresnel Reflectance

- Usually, physics table for each material's fresnal reflectance at zero degrees of incidence

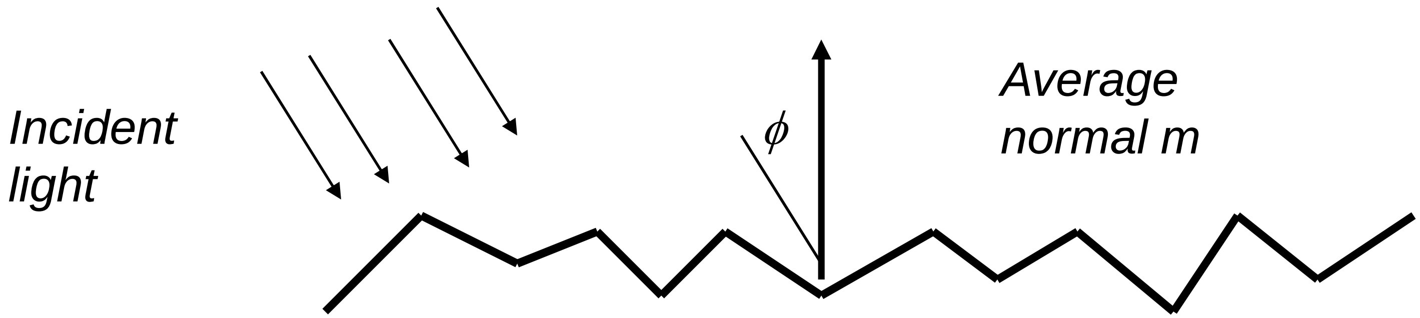
Material	Fresnel Value (R,G,B)
Water	0.02, 0.02, 0.02
Plastic	0.05, 0.05, 0.05
Glass	0.08, 0.08, 0.08
Diamond	0.17, 0.17, 0.17
Copper	0.95, 0.64, 0.54
Aluminum	0.91, 0.92, 0.92

- Schlick approximation to get arbitrary F

$$F(\theta) = F(0) + (1 - F(0))(1 - \cos\theta)^5$$

Microgeometry

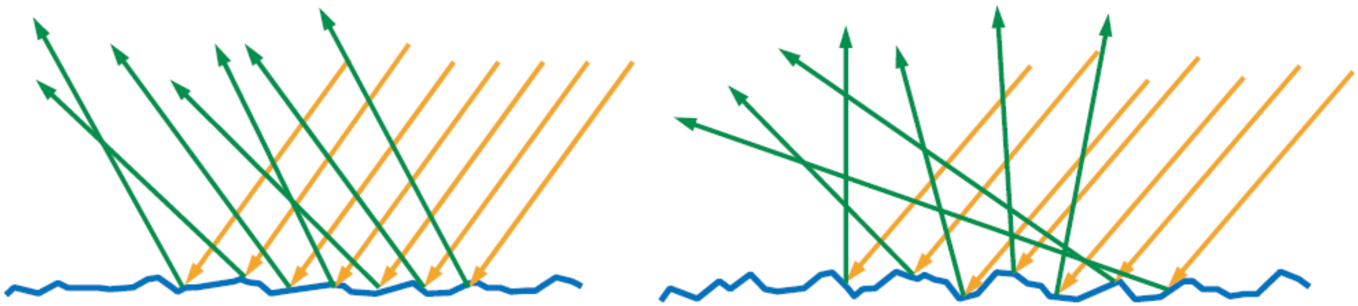
- **Basic idea:** model surfaces as made up of small V-shaped grooves or "microfacets"

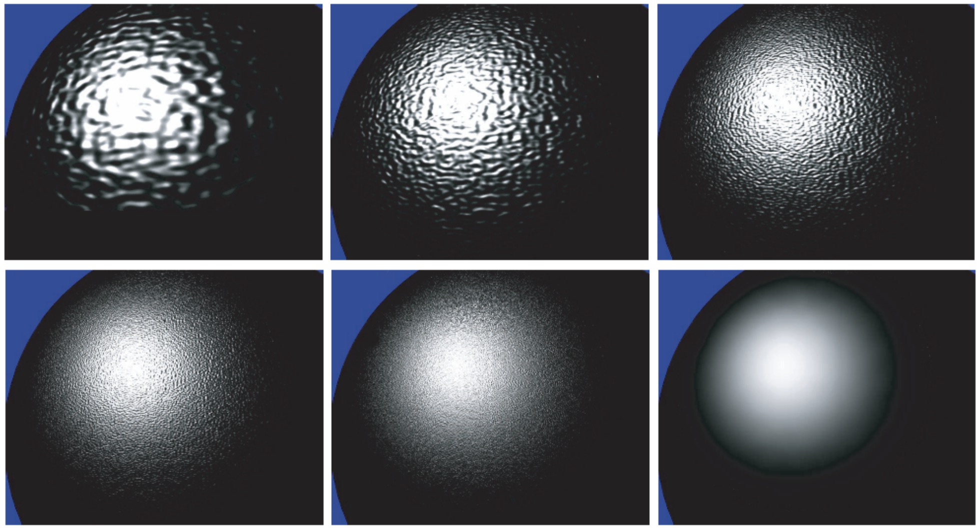


- Many grooves occur at each surface point
- Only perfectly facing grooves contribute
- Can describe distribution of (aggregate) groove directions
- E.g. half of grooves at hit point face 30 degrees, etc

Microgeometry

- Rougher surfaces bounce light all over the place

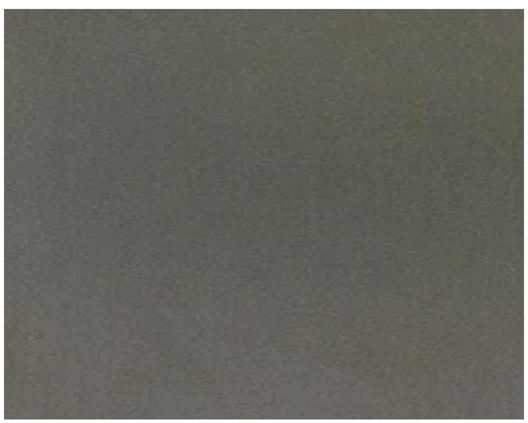




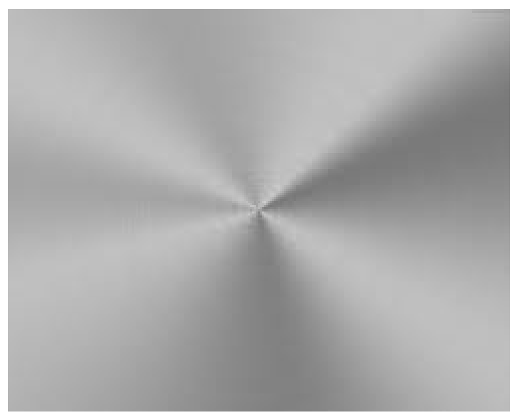
Increasing roughness

Isotropic Vs Anisotropic Surfaces

- **Isotropic:** light bounced equally in all directions
- **Anisotropic:**
  - Surface has grooves with directions. E.g. Brushed steel
  - Light bounced differently along vs across the grain.



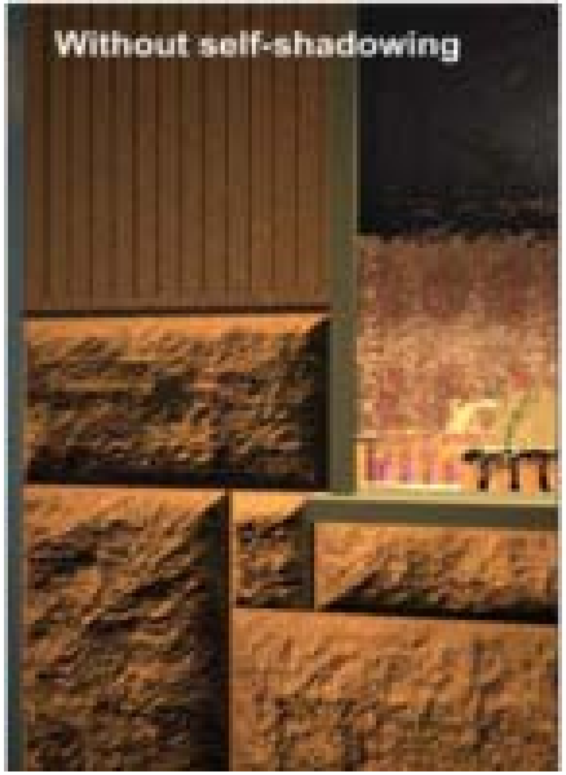
Isotropic



Anisotropic (brushed steel)

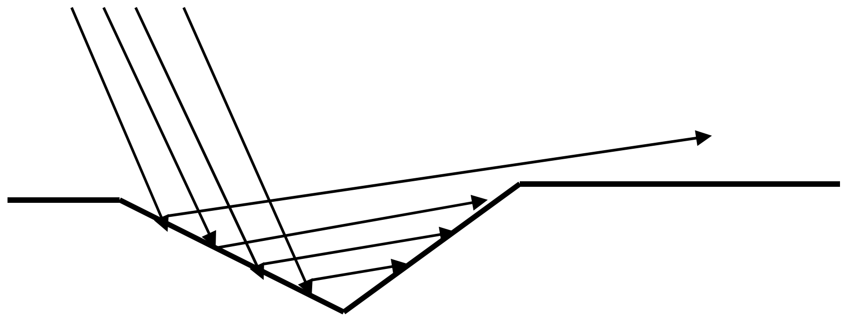
Self-Shadowing

- Some grooves on extremely rough surface may block other surfaces

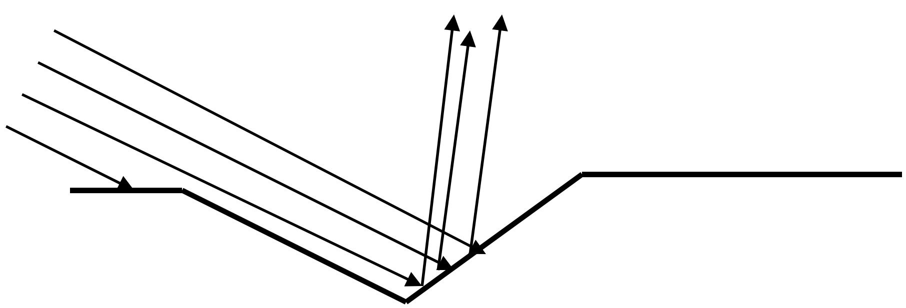


Self-Shadowing: 2 Cases

- **Masking:** No blocking of incident light, partial blocking of exitting light



- **Shadowing:** Partial blocking of incident light, no blocking of exitting light



Microfacet BRDF Models

- Microfacet BRDF models such as Cook-Torrance model assume V-shaped grooves
- Typically expressed using groove distribution, microfacet and shadowing terms.
- Example: Cook-Torrance specular term

$$\cos^{\alpha}\phi \rightarrow \frac{F(\phi,\eta)DG}{(\mathbf{m}\cdot\mathbf{v})}$$

- Where
  - D - Distribution term
  - G – Geometric term
  - F – Fresnel term

Note: ambient and diffuse terms same as Phong ambient and diffuse

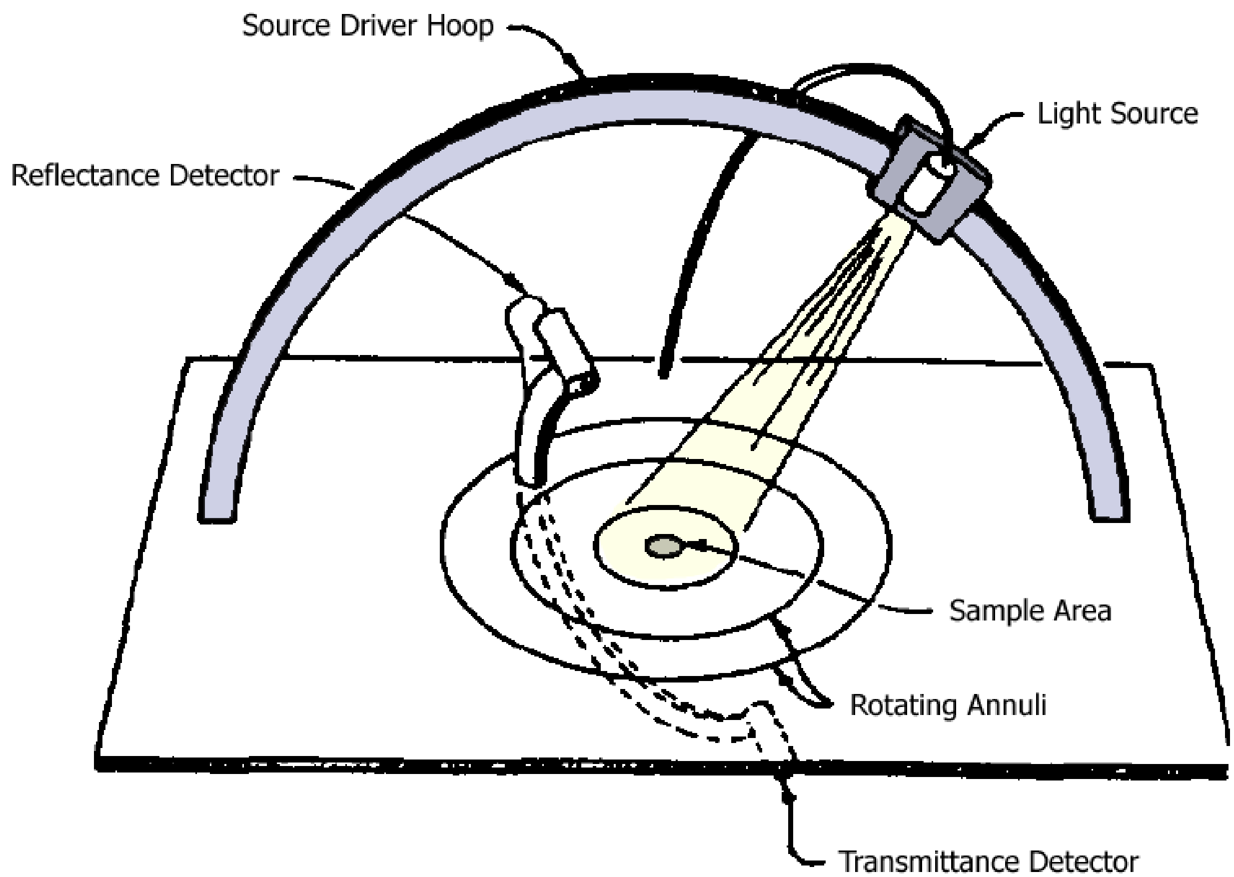
Other Microface BRDF Models

- **Oren-Nayar** – Lambertian not specular
- **Aishikhminn-Shirley** – Grooves not v-shaped. Other Shapes
- Microfacet generator

BRDF Evolution

- BRDFs have evolved historically
- 1970's: Empirical models
  - Phong's illumination model
- 1980s:
  - Physically based models
  - Microfacet models (e.g. Cook Torrance model)
- 1990's
  - Physically-based appearance models of specific effects (materials, weathering, dust, etc)
- Early 2000's
  - Measurement & acquisition of static materials/lights (wood, translucence, etc)
- Late 2000's
  - Measurement & acquisition of time-varying BRDFs (ripening, etc)

Measuring BRDFs



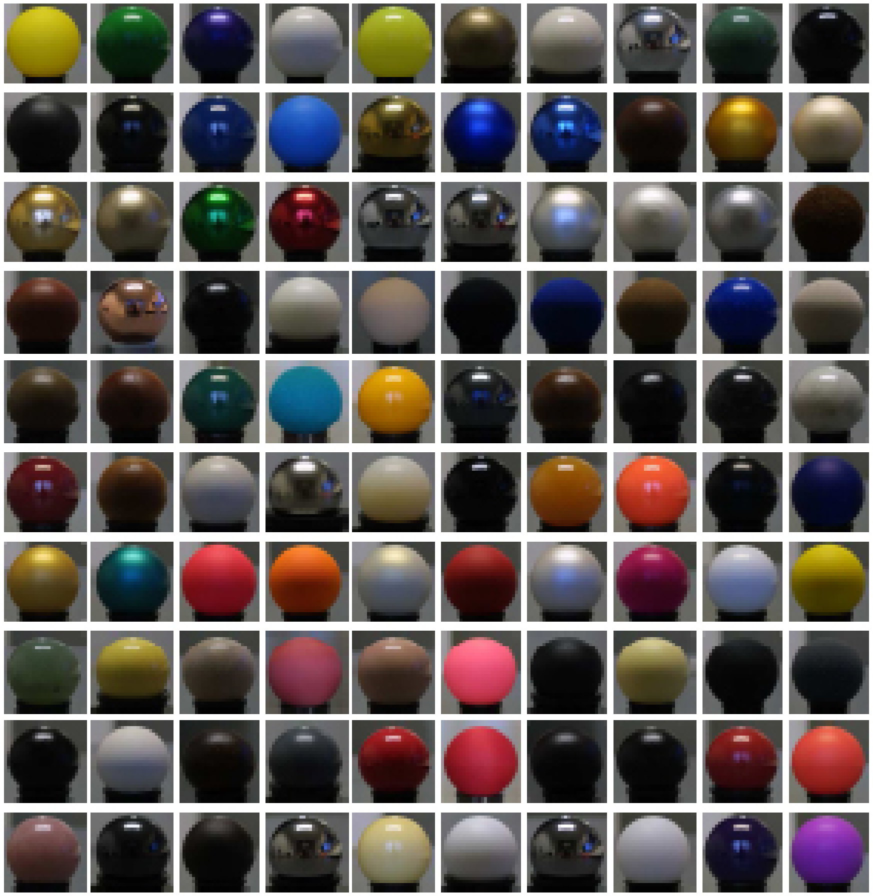
Murray-Coleman and Smith Gonioreflectometer. (Copied and Modified from [Ward92]).

Measured BRDF Samples

- Mitsubishi Electric Research Lab (MERL)

http://www.merl.com/brdf/

- Wojciech Matusik
- MIT PhD Thesis
- 100 Samples



Time-varying BRDF

- BRDF: How different materials reflect light
- Time varying?: how reflectance changes over time
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Final Words

- **Multipass Rendering**
  - Use multiple shaders to process lights
  - Render 1 light source per shader
  - Sum results up in framebuffer
- **Deferred Shading**
  - Calculate visibility first, no shading
  - After all visibility calculations, shade only closest surface

References

- Chapter 6-7 of RT Rendering 3rd edition
- CS 543/4731 course slides
- UIUC CS 319, Advanced Computer Graphics Course
- David Luebke, CS 446, U. of Virginia, slides
- Hanspeter Pfister, CS 175 Introduction to Computer Graphics, Harvard Extension School, Fall 2010 slides
- Christian Miller, CS 354, Computer Graphics, U. of Texas, Austin slides, Fall 2011
- Ulf Assarsson, TDA361/DIT220 - Computer graphics 2011, Chalmers Instititute of Tech, Sweden