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CS-184: Computer Graphics

Lecture #3: Shading

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Today

- Local Illumination & Shading
  - The BRDF
  - Simple diffuse and specular approximations
  - Shading interpolation: flat, Gouraud, Phong
  - Some miscellaneous tricks

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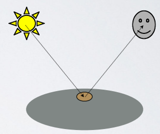
Local Shading

- Local: consider in isolation
  - 1 light
  - 1 surface
  - The viewer
- Recall: lighting is linear
  - Almost always...



Counter example: photochromatic materials

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Local Shading

- Examples of non-local phenomena
  - Shadows
  - Reflections
  - Refraction
  - Indirect lighting

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The BRDF

- The **B**i-directional **R**eflectance **D**istribution **F**unction
- Given
  - Surface material
  - Incoming light direction
  - Direction of viewer
  - Orientation of surface
- Return:
  - fraction of light that reaches the viewer
- We'll worry about physical units later...

$$\rho = \rho(\theta_V, \theta_L)$$
$$= \rho(\mathbf{v}, \mathbf{l}, \mathbf{n})$$

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The BRDF

Ideal specular

- **Perfect mirror reflection**

Ideal diffuse

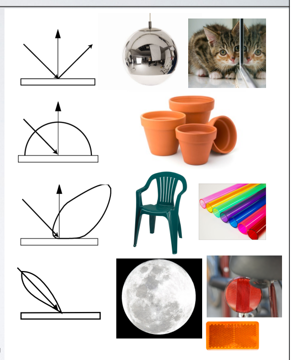
- **Equal reflection in all directions**

Glossy specular

- **Majority of light reflected near mirror direction**

Retro-reflective

- **Light reflected back towards light source**



Diagrams illustrate how light from incoming direction is reflected in various outgoing directions.

Ren Ng

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The BRDF

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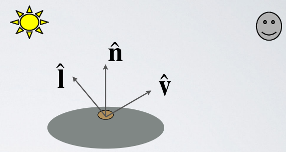
$\rho(\mathbf{v}, \mathbf{l}, \mathbf{n})$



- Spatial variation capture by "the material"
- Frequency dependent
  - Typically use separate RGB functions
  - Does not work perfectly
  - Better:

$$\rho = \rho(\theta_V, \theta_L, \lambda_{\text{in}}, \lambda_{\text{out}})$$

Obtaining BRDFs

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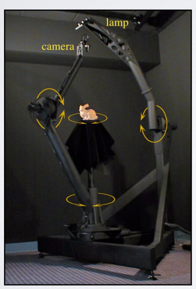
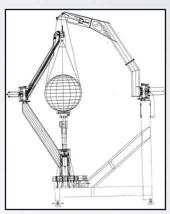
- Measure from real materials





Images from Marc Levoy

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Obtaining BRDFs

- Measure from real materials
- Computer simulation
  - Simple model + complex geometry
- Derive model by analysis
- Make something up

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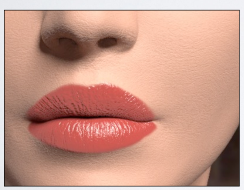
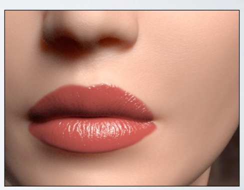
Beyond BRDFs

- The BRDF model does not capture everything
  - e.g. Subsurface scattering (BSSRDF)





Images from Jensen *et. al, SIGGRAPH 2001*

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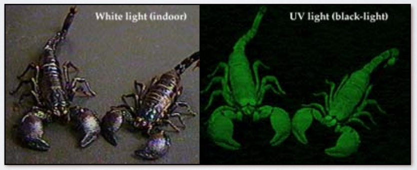
Beyond BRDFs

- The BRDF model does not capture everything
  - e.g. Inter-frequency interactions



$\rho = \rho(\theta_V, \theta_L, \lambda_{in}, \lambda_{out})$ This version would work....

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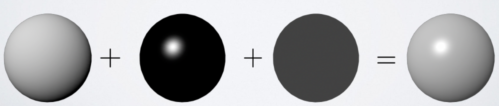
A Simple Model

- Approximate BRDF as sum of
  - A diffuse component
  - A specular component
  - A "ambient" term



Diffuse Component

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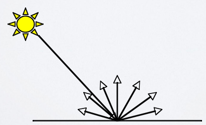
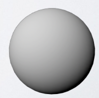
- Lambert's Law
  - Intensity of reflected light proportional to cosine of angle between surface and incoming light direction
  - Applies to "diffuse," "Lambertian," or "matte" surfaces
  - Independent of viewing angle
- Use as a component of non-Lambertian surfaces





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Diffuse Component

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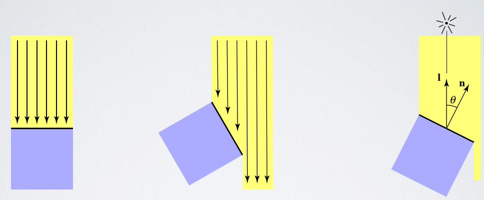

Top face of cube receives a certain amount of light

Top face of 60° rotated cube intercepts half the light

In general, light per unit area is proportional to $\cos\theta = \mathbf{l} \cdot \mathbf{n}$

Steve Marschner

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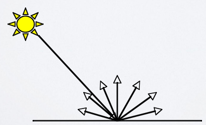
Diffuse Component

Comment about two-side lighting in text is wrong...

$$k_d I(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})$$

$$\max(k_d I(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}), 0)$$



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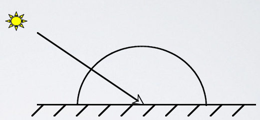
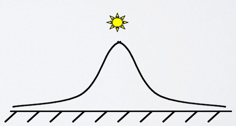
Diffuse Component

- Plot light leaving in a given direction:



- Plot light leaving from each point on surface



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Specular Component

- Specular component is a mirror-like reflection
- Phong Illumination Model
  - A reasonable approximation for some surfaces
  - Fairly cheap to compute
- Depends on view direction

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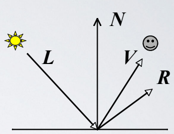
Specular Component

$$k_s I (\hat{\mathbf{r}} \cdot \hat{\mathbf{v}})^p$$

$$k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$



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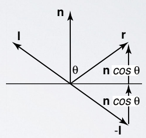
Specular Component

- Computing the reflected direction

$$\hat{\mathbf{r}} = -\hat{\mathbf{l}} + 2(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$



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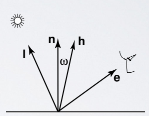
Specular Component

- "Half-angle" approximation for specular

$$\hat{\mathbf{h}} = \frac{\hat{\mathbf{l}} + \hat{\mathbf{v}}}{||\hat{\mathbf{l}} + \hat{\mathbf{v}}||}$$



different specular term $k_s I(\hat{\mathbf{h}} \cdot \hat{\mathbf{n}})^p$

Don't use half-angle approximation in your assignments!

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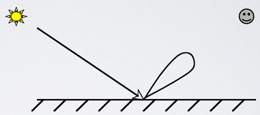
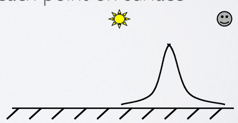
Specular Component

- Plot light leaving in a given direction:



- Plot light leaving from each point on surface



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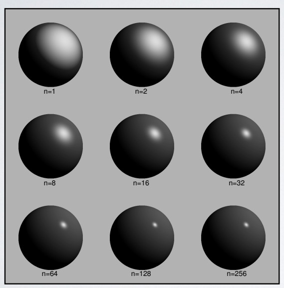
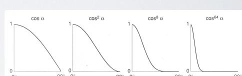
Specular Component

- Specular exponent sometimes called "roughness"





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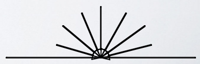
Ambient Term

- Really, its a cheap hack
- Accounts for "ambient, omnidirectional light"
- Without it everything looks like it's in space



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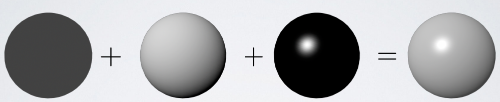
Summing the Parts

$$R = k_a I + k_d I \max(\hat{\mathbf{l}} \cdot \hat{\mathbf{n}}, 0) + k_s I \max(\hat{\mathbf{r}} \cdot \hat{\mathbf{v}}, 0)^p$$



- Recall that the $k_?$ are by wavelength
  - RGB in practice
- Sum over all lights

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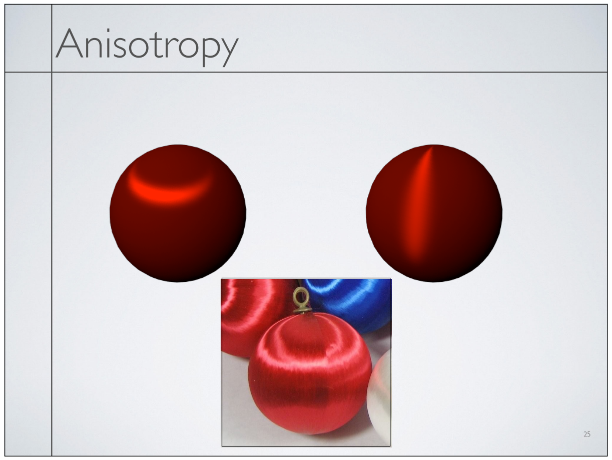

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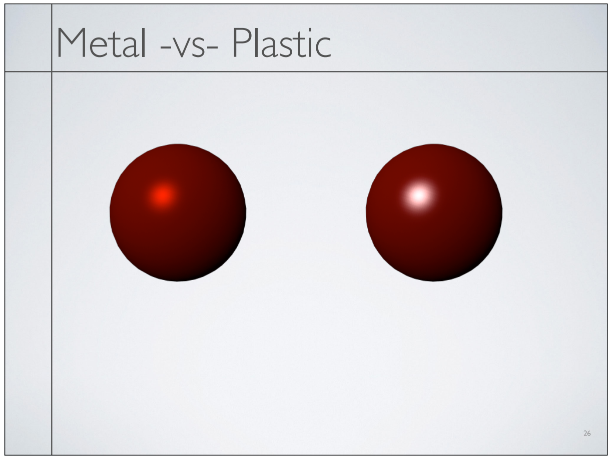

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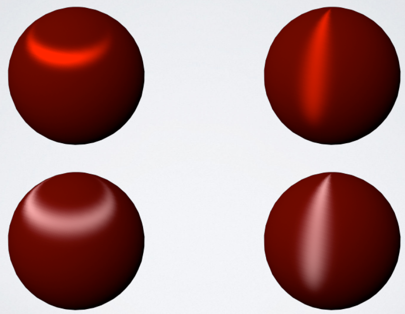
Metal -vs- Plastic



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Other Color Effects

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Materials: Paint

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Materials: Paint

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Materials: Mirror

Ren Ng

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Materials: Metallic

Ren Ng

Other Color Effects

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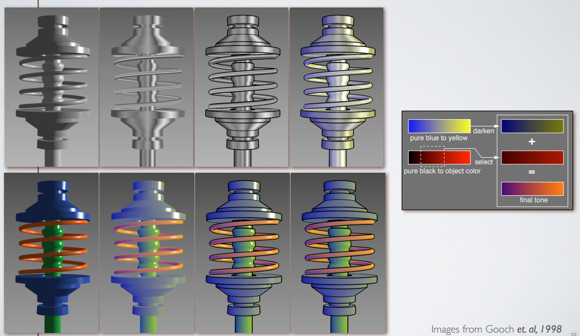

Images from Gooch *et. al*, 1998

Measured BRDFs

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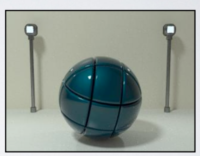

BRDFs for automotive paint

Images from Cornell University Program of Computer Graphics

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Measured BRDFs


BRDFs for aerosol spray paint

Images from Cornell University Program of Computer Graphics 37

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Measured BRDFs

BRDFs for house paint

Images from Cornell University Program of Computer Graphics 38

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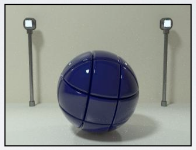
Measured BRDFs



BRDFs for lucite sheet

Images from Cornell University Program of Computer Graphics

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Ashikhmin-Shirley BRDF

- More realistic specular term (for some materials)
- Anisotropic specularities
- Fresnel behavior (grazing angle highlights)
- Energy preserving diffuse term
- Sum of diffuse and specular terms (as before)

$$\rho(\hat{\mathbf{l}}, \hat{\mathbf{v}}) = \rho_d(\hat{\mathbf{l}}, \hat{\mathbf{v}}) + \rho_s(\hat{\mathbf{l}}, \hat{\mathbf{v}})$$

Michael Ashikhmin and Peter Shirley. 2000. An anisotropic phong BRDF model. J. Graph. Tools 5, 2 (February 2000), 25-32.
https://www.cs.utah.edu/~shirley/papers/jgtbrdf.pdf

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Ashikhmin-Shirley BRDF

$$\rho_s(\hat{\mathbf{l}}, \hat{\mathbf{e}}) = \frac{\sqrt{(p_u+1)(p_v+1)}}{8\pi} \frac{(\hat{\mathbf{n}} \cdot \hat{\mathbf{h}})^{p_u \cos^2\phi + p_v \sin^2\phi}}{(\hat{\mathbf{h}} \cdot \hat{\mathbf{e}}) \max\left((\hat{\mathbf{n}} \cdot \hat{\mathbf{e}}), (\hat{\mathbf{n}} \cdot \hat{\mathbf{l}})\right)} F(\hat{\mathbf{h}} \cdot \hat{\mathbf{e}})$$

$$F(\hat{\mathbf{h}} \cdot \hat{\mathbf{e}}) = K_s + (1 - K_s)(1 - (\hat{\mathbf{h}} \cdot \hat{\mathbf{e}}))^5$$

- $\hat{\mathbf{l}}$ Light direction
- $\hat{\mathbf{e}}$ Viewer (eye) direction
- p_u, p_v Specular powers
- $\hat{\mathbf{n}}$ Normal
- $\hat{\mathbf{h}}$ Half angle
- K_s Specular coefficient (color)
- $\hat{\mathbf{u}}, \hat{\mathbf{v}}$ Parametric directions

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Ashikhmin-Shirley BRDF

$$\rho_s(\hat{\mathbf{l}}, \hat{\mathbf{e}}) = \frac{\sqrt{(p_u+1)(p_v+1)}}{8\pi} \frac{(\hat{\mathbf{n}} \cdot \hat{\mathbf{h}})^{\frac{p_u(\hat{\mathbf{h}} \cdot \hat{\mathbf{u}})^2 + p_u(\hat{\mathbf{h}} \cdot \hat{\mathbf{v}})^2}{1 - (\hat{\mathbf{h}} \cdot \hat{\mathbf{n}})^2}}}{(\hat{\mathbf{h}} \cdot \hat{\mathbf{e}}) \max\left((\hat{\mathbf{n}} \cdot \hat{\mathbf{e}}), (\hat{\mathbf{n}} \cdot \hat{\mathbf{l}})\right)} F(\hat{\mathbf{h}} \cdot \hat{\mathbf{e}})$$

$$F(\hat{\mathbf{h}} \cdot \hat{\mathbf{e}}) = K_s + (1 - K_s)(1 - (\hat{\mathbf{h}} \cdot \hat{\mathbf{e}}))^5$$

Approximate Fresnel function

- $\hat{\mathbf{l}}$ Light direction
- $\hat{\mathbf{e}}$ Viewer (eye) direction
- p_u, p_v Specular powers
- $\hat{\mathbf{n}}$ Normal
- $\hat{\mathbf{h}}$ Half angle
- K_s Specular coefficient (color)
- $\hat{\mathbf{u}}, \hat{\mathbf{v}}$ Parametric directions

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Ashikhmin-Shirley BRDF

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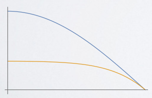
$$\rho_d(\hat{\mathbf{l}},\hat{\mathbf{e}}) = \frac{28K_d}{23\pi}(1-K_s)\left(1-\left(1-\frac{\hat{\mathbf{n}}\cdot\hat{\mathbf{e}}}{2}\right)^5\right)\left(1-\left(1-\frac{\hat{\mathbf{n}}\cdot\hat{\mathbf{l}}}{2}\right)^5\right)$$

Note: The Phong diffuse term (Lambertian) is independent of view. But this term accounts for unavailable light due to specular/Fresnel reflection.



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Ashikhmin-Shirley BRDF

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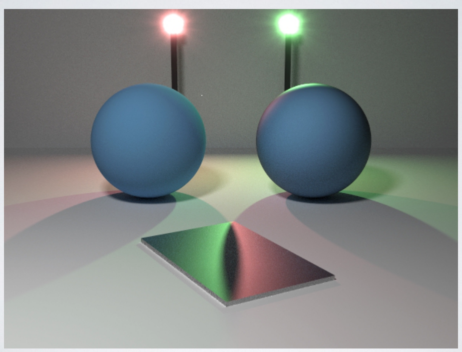

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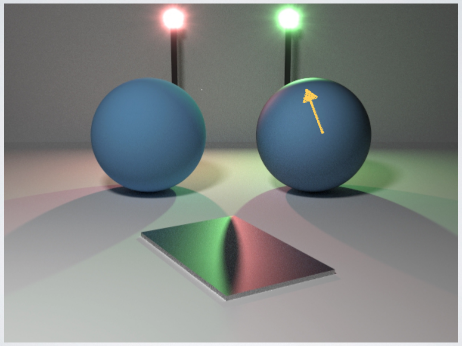
Ashikhmin-Shirley BRDF



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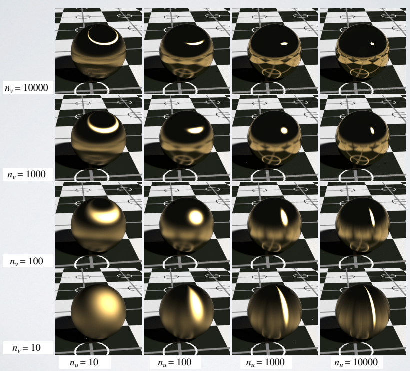
Ashikhmin-Shirley BRDF



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Details Beget Realism

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- The "computer generated" look is often due to a lack of fine/subtle details... a lack of richness.

From bustledress.com

Details Beget Realism

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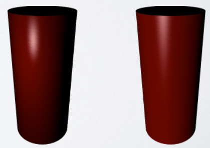
Direction -vs- Point Lights

- For a point light, the light direction changes over the surface
- For "distant" light, the direction is constant
- Similar for orthographic/perspective viewer



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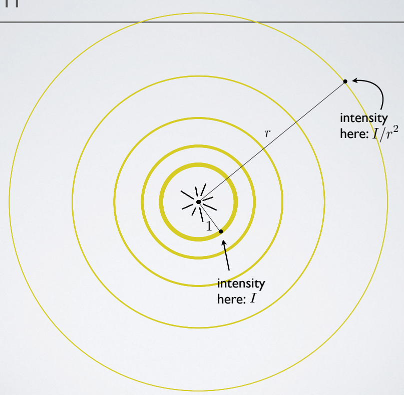
Falloff



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Falloff

- Physically correct: $1/r^2$ light intensify falloff
  - Tends to look bad (why?)
  - Not used in practice
- Sometimes compromise of $1/r$ used

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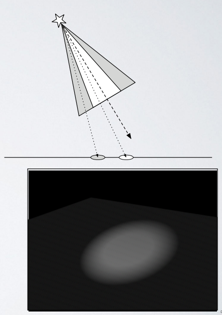
Spot and Other Lights

- Other calculations for useful effects
  - Spot light
  - Only light certain objects
  - Negative lights
  - *etc.*



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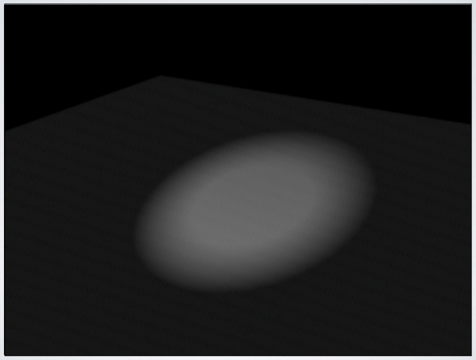
Ugly....



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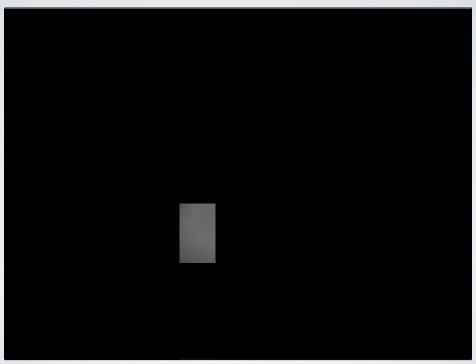
Ugly....



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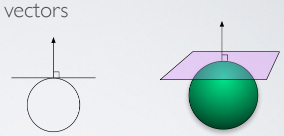
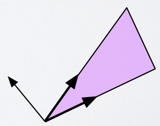
Surface Normals

- The normal vector at a point on a surface is perpendicular to all surface tangent vectors



- For triangles normal given by right-handed cross product



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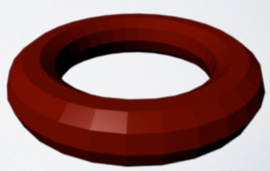
Flat Shading

- Use constant normal for each triangle (polygon)
  - Polygon objects don't look smooth
  - Faceted appearance very noticeable, especially at specular highlights
  - Recall mach bands...



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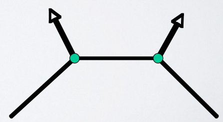
Smooth Shading

- Compute "average" normal at vertices
- Interpolate across polygons
- Use threshold for "sharp" edges
  - Vertex may have different normals for each face



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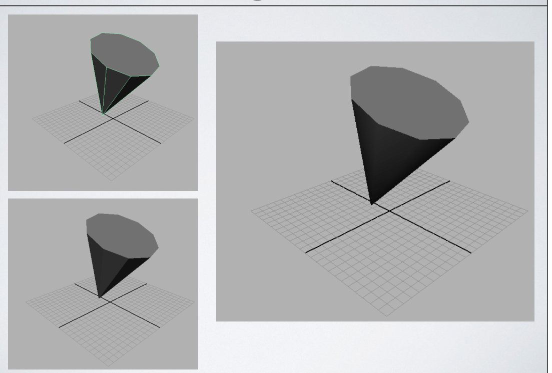
Smooth Shading



Smooth Shading

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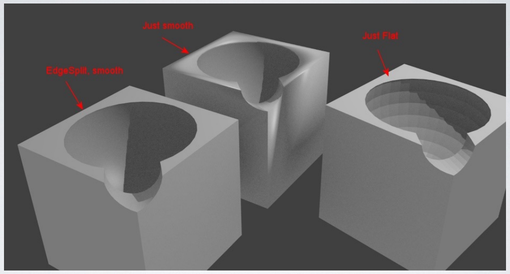

From blender.stackexchange.com

Gouraud Shading

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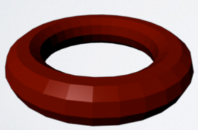
- Compute shading at each vertex
  - Interpolate colors from vertices
  - Pros: fast and easy, looks smooth
  - Cons: terrible for specular reflections



Flat

Gouraud

Note: Gouraud was hardware rendered...

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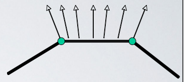
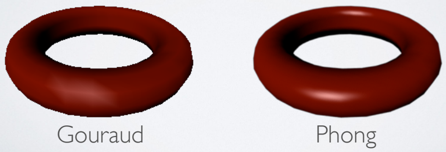
Phong Shading

- Compute shading at each pixel
  - Interpolate ***normals*** from vertices
  - Pros: looks smooth, better speculars
  - Cons: expensive





Note: Gouraud was hardware rendered...