VGP351 – Week 5

- Agenda:
  - Quiz #2
  - Physical theory of light
  - Lighting models for graphics
  - Shading models for graphics
  - Types of lights

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Lighting

- Lighting, in graphics, is the art of *approximately* simulating the manner in which light interacts with materials

Lighting

- Lighting, in graphics, is the art of *approximately* simulating the manner in which light interacts with materials
- Remember:

  "Light makes right."

  – Andrew Glassner

  "If it looks good, it is good."

  – Michael Abrash

Lighting

- Two fundamental theories of how light works
  - Wave theory of light – Christiaan Huygens proposed in 1690 that light is emitted in all directions as a series of waves

Double-Slit Experiment

- Thomas Young's 1801 double-slit experiment supports the wave theory
  - Light emitted through two thin slits causes alternating light and dark bands projected on a surface

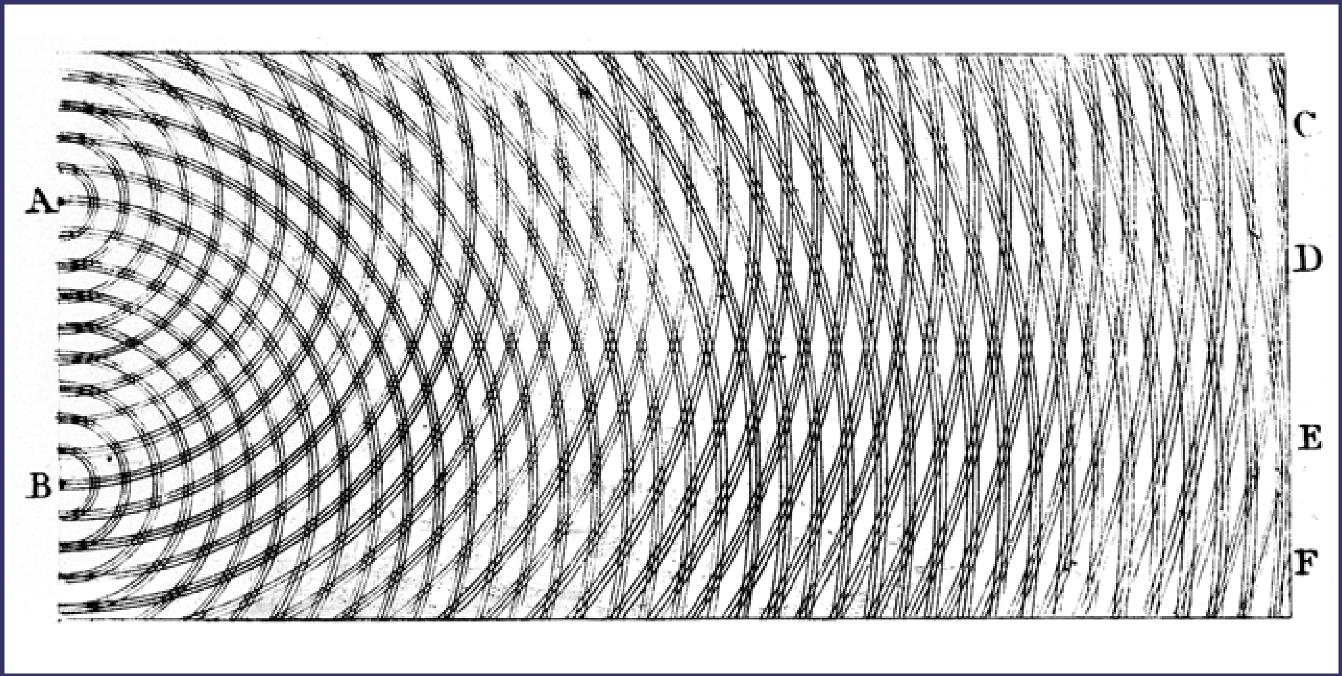


Image from http://en.wikipedia.org/wiki/File:Young_Diffraction.png

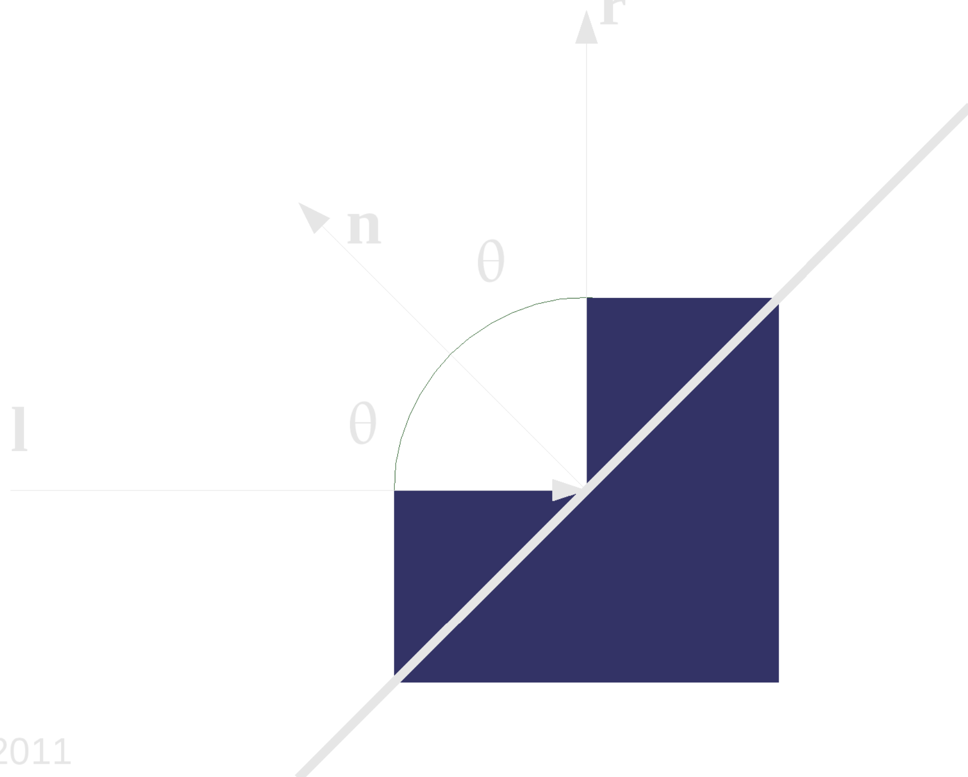
Lighting

- Two fundamental theories of how light works
  - Wave theory of light – Christiaan Huygens proposed in 1690 that light is emitted in all directions as a series of waves
  - Particle theory of light – Ibn al-Haytham proposed in 1021 that light beams are made of minuscule energy particles that travel in a straight line at a fixed speed

Ibn al-Haytham

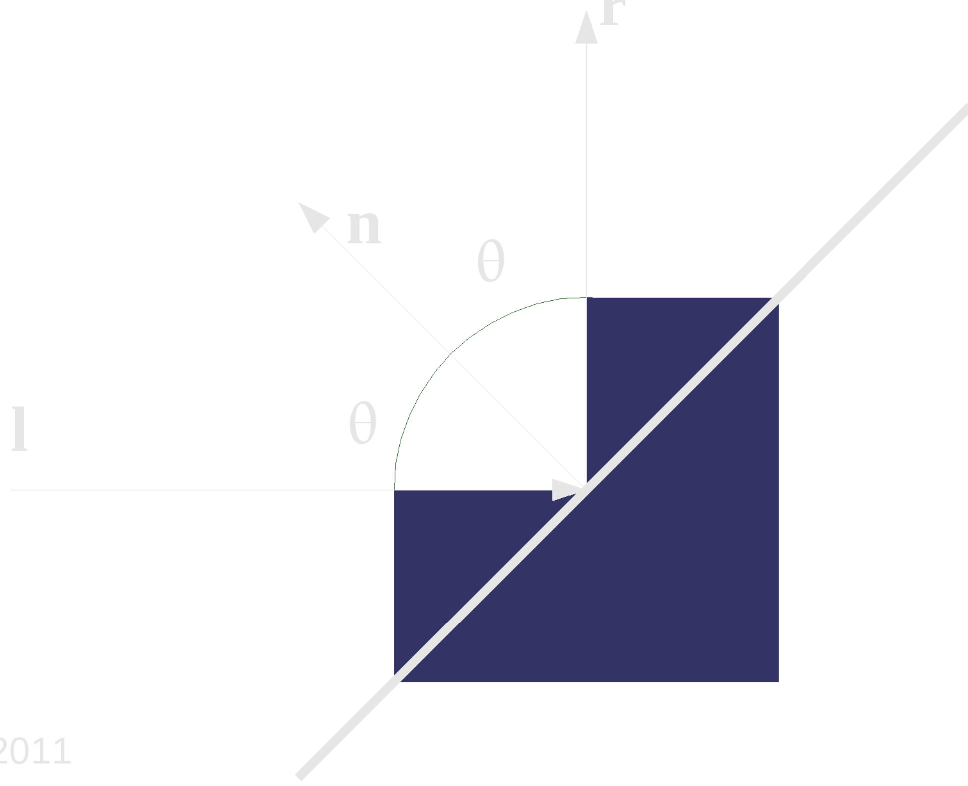
Particle Theory – Reflection

- Particle theory of light correctly predicts reflection



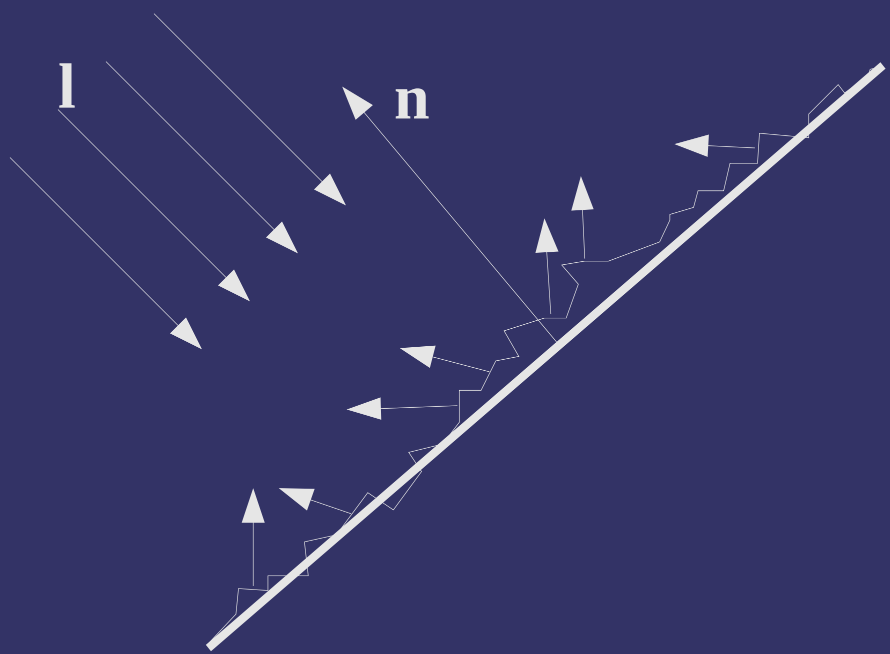
Particle Theory – Reflection

- Particle theory of light correctly predicts reflection
  - This perfect, mirror-like reflection is called *specular reflection*



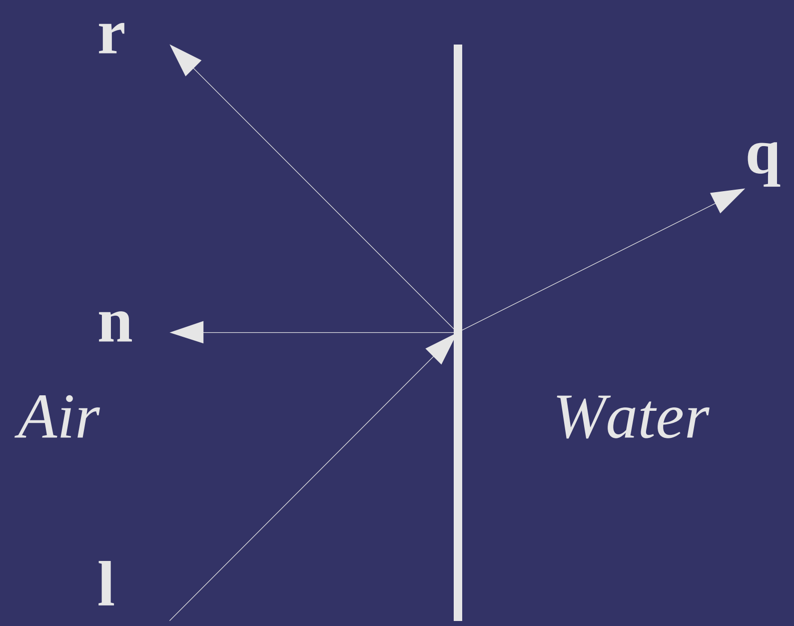
Particle Theory – Reflection

- What about "rough" surfaces?
  - Light rays scatter in all directions
  - This is called *diffuse reflection*



Wave Theory – Refraction

- When light leaves one material and enters another, it changes direction
  - At the *interface* the speed changes, and the light bends



Wave Theory – Refraction

Image from http://en.wikipedia.org/wiki/File:Refraction-with-soda-straw.jpg

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Ibn al-Haytham

- So... which is it?
  - It exhibits *both* characteristics depending on the situation
  - See also http://dir.salon.com/story/comics/tomo/2004/07/06/tomo/

Computer Lighting Models

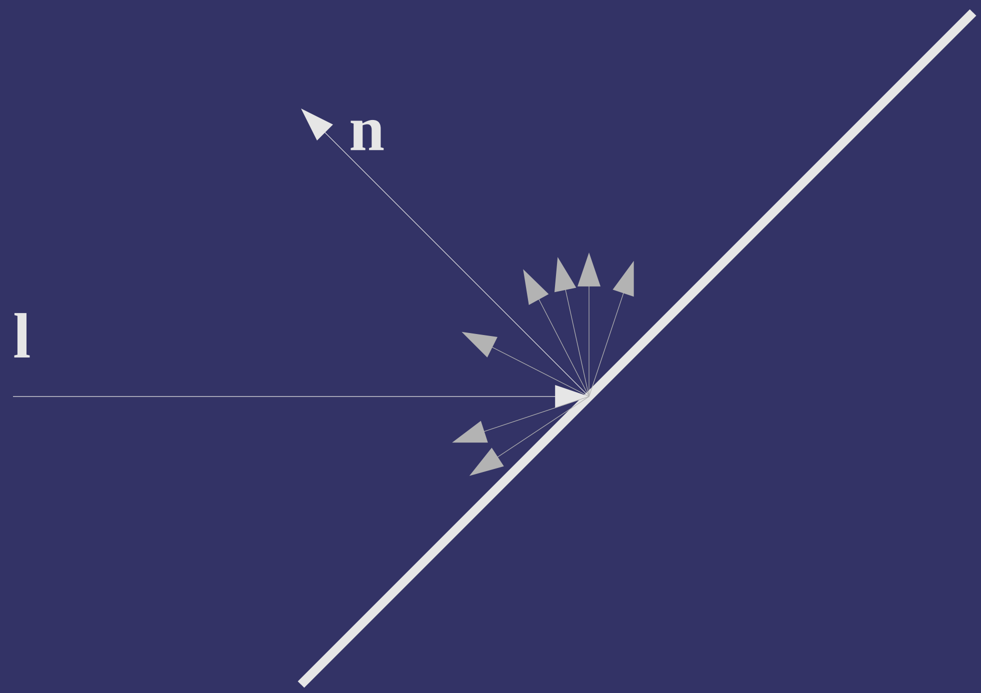
- Every model is a simplification of the physical phenomena
  - We'll look at three *simple* models today:
    - Lambertian reflection model
    - Phong reflection model
    - Blinn-Phong reflection model
  - We'll look at a number of more complex models next term

Lambertian Reflectance

- Reflection from ideal diffuse reflectors obeys Lambert's Cosine Law:

  > The radiant intensity reflected is proportional to the cosine between surface normal and the incoming light

Lambertian Reflectance



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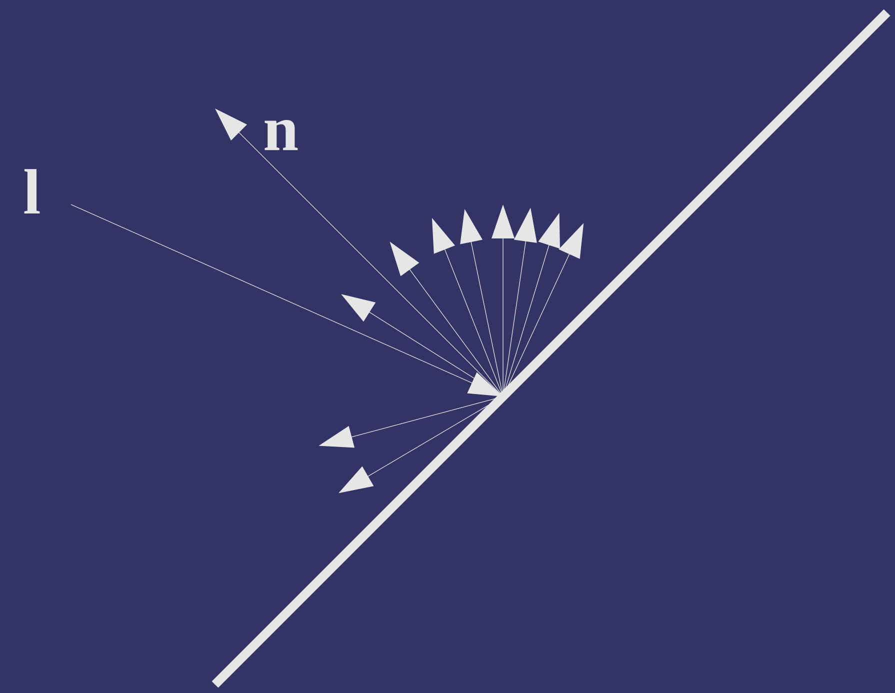
Lambertian Reflectance



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$$\mathbf{i}_d = \frac{\mathbf{l} \cdot \mathbf{n}}{|\mathbf{l}||\mathbf{n}|} * \mathbf{c}_d * \mathbf{l}_d$$

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Vector from the surface to the light

Intensity of the light

Diffuse color of the surface

Lambertian Reflectance

- Reflection from ideal diffuse reflectors obeys Lambert's Cosine Law:

$$\mathbf{i}_d = \frac{\max(\mathbf{n} \cdot \mathbf{l}, 0)}{|\mathbf{n}||\mathbf{l}|} * \mathbf{c}_d * \mathbf{l}_d$$

Why is this necessary?

Lambertian Reflectance

- Reflection from ideal diffuse reflectors obeys Lambert's Cosine Law:

$$\mathbf{i}_d = \frac{\max(\mathbf{n}\cdot\mathbf{l}, 0)}{|\mathbf{n}||\mathbf{l}|} * \mathbf{c}_d * \mathbf{l}_d$$

Because $\mathbf{n}\cdot\mathbf{l}$ can be negative. Negative light is nonsense!

Lambertian Reflectance

- Reflection from ideal diffuse reflectors obeys Lambert's Cosine Law:

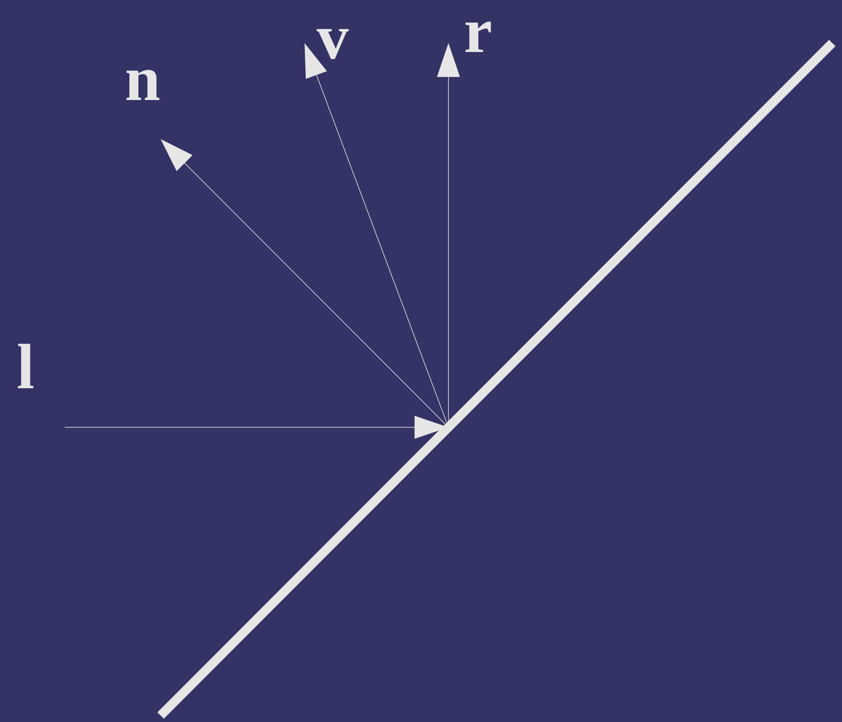
$$\mathbf{i}_d = \frac{\max(\mathbf{n} \cdot \mathbf{l}, 0)}{|\mathbf{n}||\mathbf{l}|} * \mathbf{c}_d * \mathbf{l}_d$$

- Note: viewer is <u>*not*</u> involved in this calculation
  - Hence, diffuse lighting is *view independent*

Phong Reflectance

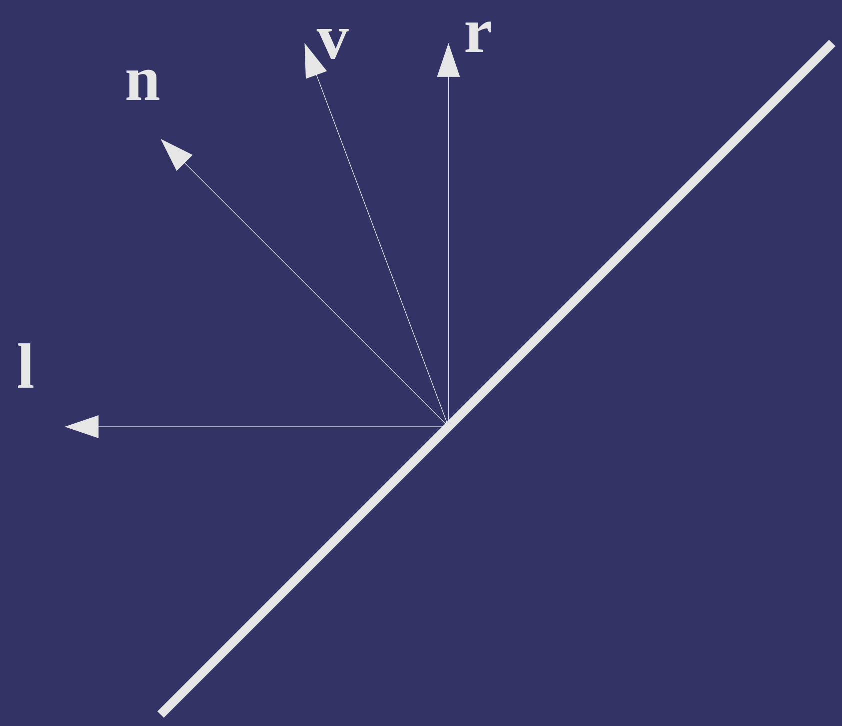
- Adds a mirror-like reflection factor to the diffuse factor

$$\mathbf{i}_s = \left(\frac{\mathbf{r} \cdot \mathbf{v}}{|\mathbf{r}||\mathbf{v}|} \right)^s * \mathbf{c}_s * \mathbf{l}_s$$



Phong Reflectance

- Adds a mirror-like reflection factor to the diffuse factor
  - **n**, **v**, and **l** are known in advance, but **r** is not...but it can be calculated in a few steps



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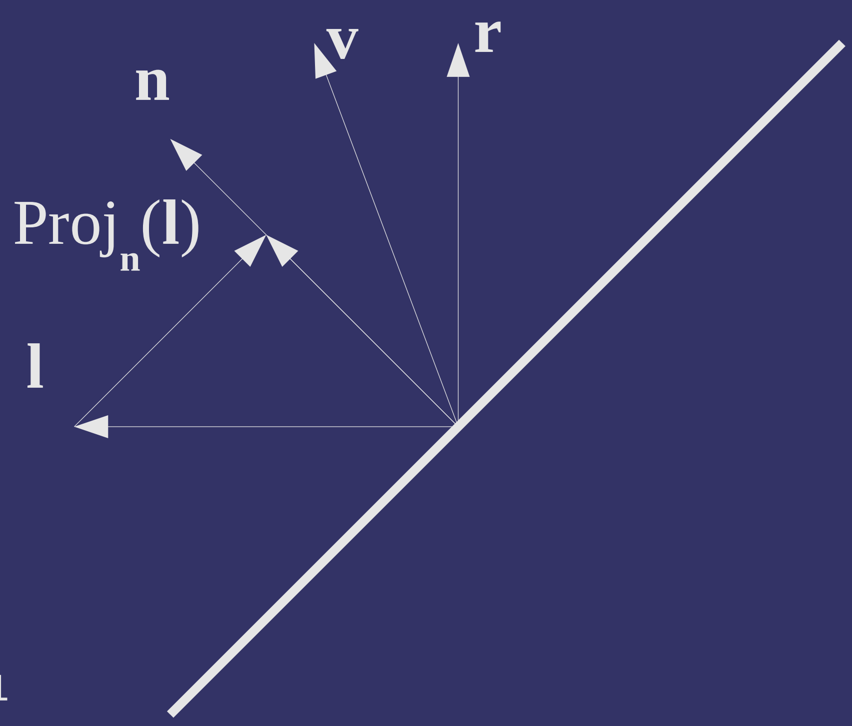

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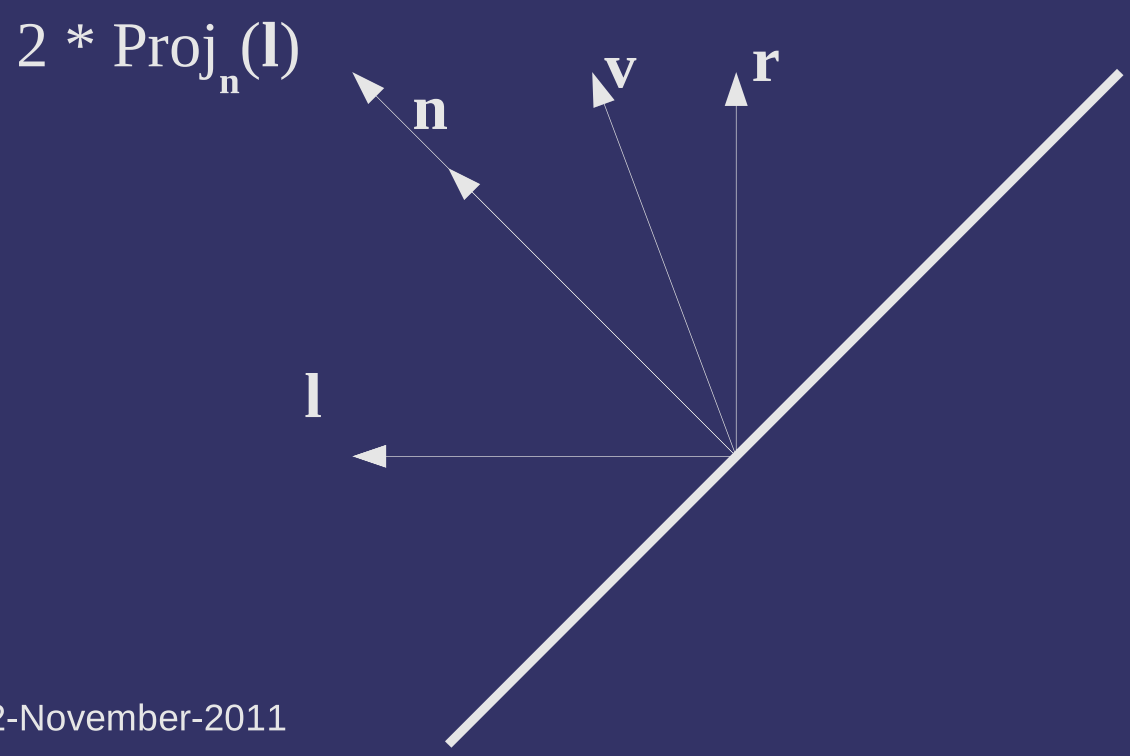

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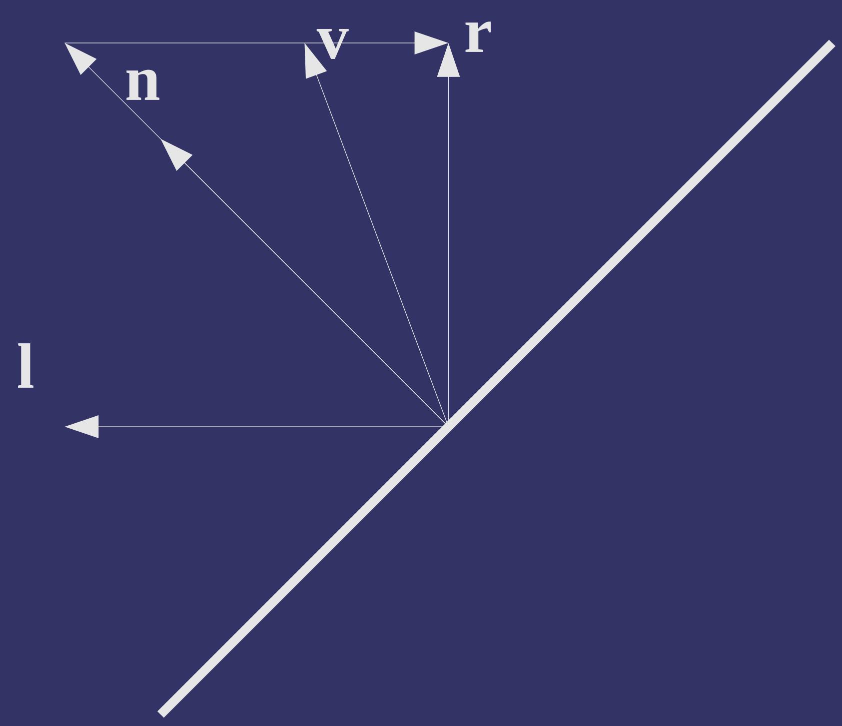
$$2 * \mathrm{Proj}_{\mathbf{n}}(\mathbf{l}) - \mathbf{l}$$



Phong Reflectance

- Adds a mirror-like reflection factor to the diffuse factor
  - $\mathbf{n}$, $\mathbf{v}$, and $\mathbf{l}$ are known in advance, but $\mathbf{r}$ is not...but it can be calculated in a few steps

$$\mathbf{r} = \frac{2(\mathbf{n} \cdot \mathbf{l})}{|\mathbf{n}||\mathbf{l}|}\mathbf{n} - \mathbf{l}$$

$$\mathbf{i}_\mathrm{s} = \left(\frac{\mathbf{r} \cdot \mathbf{v}}{|\mathbf{r}||\mathbf{v}|}\right)^{s} * \mathbf{c}_\mathrm{s} * \mathbf{l}_\mathrm{s}$$

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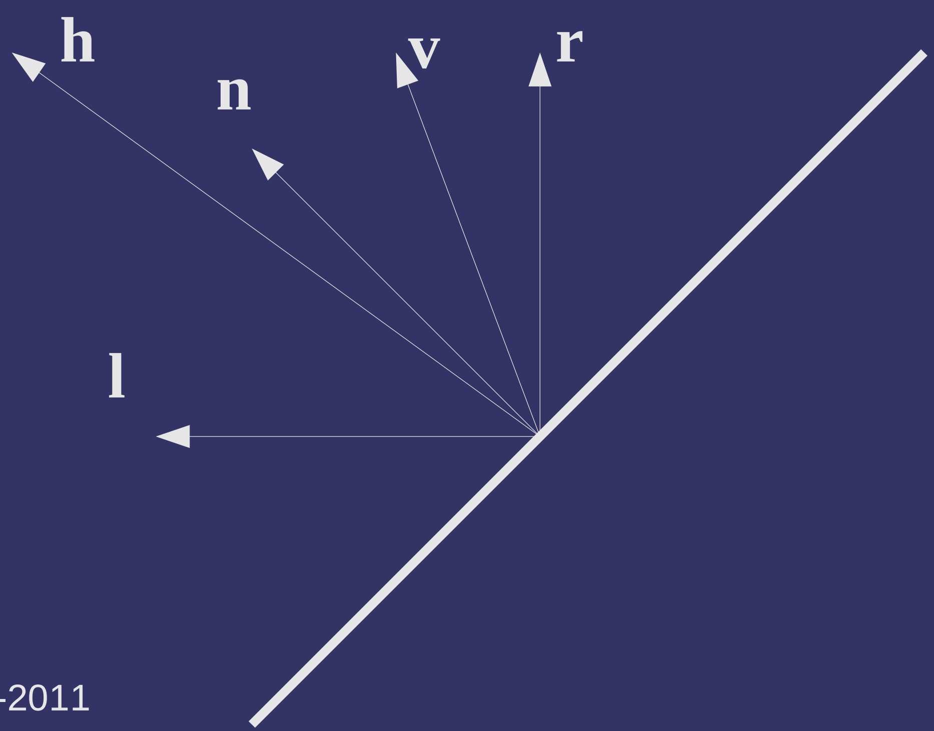
$$\mathbf{i}_s = \left(\frac{\mathbf{r} \cdot \mathbf{v}}{|\mathbf{r}||\mathbf{v}|}\right)^s * \mathbf{c}_s * \mathbf{l}_s$$

  - This is a lot of math... very expensive to calculate.

Blinn-Phong Reflectance

- James Blinn improved Phong's model in 1977
  - Define a vector **h** half way between **v** and **l**
  - Observed that as **v·r** increases, so does **n·h**



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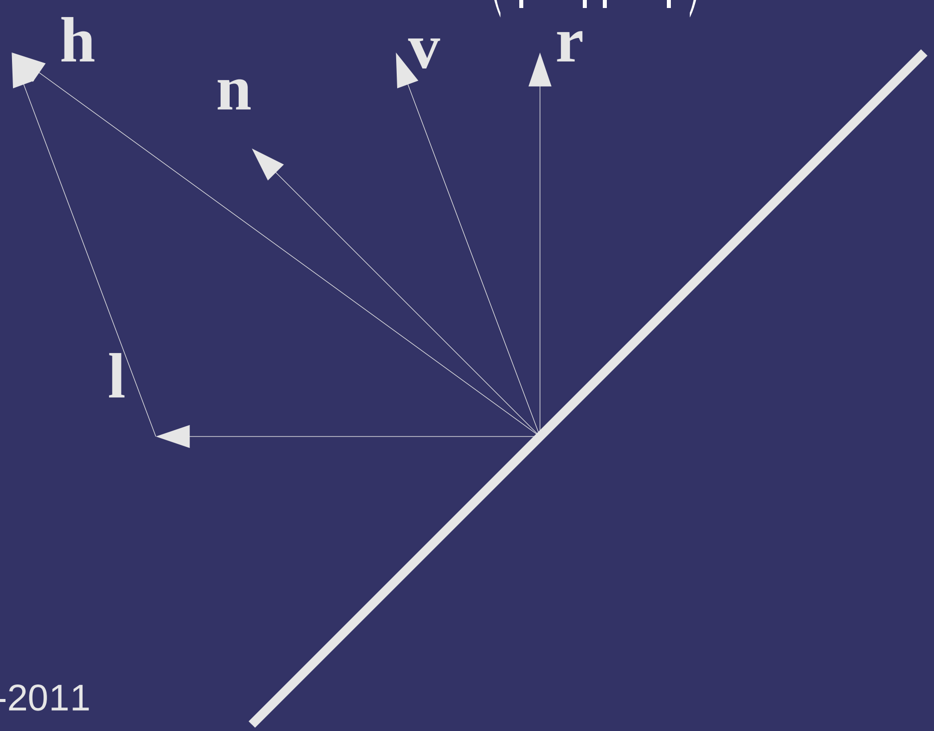
Blinn-Phong Reflectance

- James Blinn improved Phong's model in 1977
  - Observed that as $\mathbf{v}\cdot\mathbf{r}$ increases, so does $\mathbf{n}\cdot\mathbf{h}$, where $\mathbf{h}$ is a vector half way between $\mathbf{v}$ and $\mathbf{l}$

$$\mathbf{h}=\mathbf{l}+\mathbf{v}, \mathbf{i}_s=\left(\frac{\mathbf{n}\cdot\mathbf{h}}{|\mathbf{n}||\mathbf{h}|}\right)^s * \mathbf{c}_s * \mathbf{l}_s$$



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Shininess

- What is the magic s in the exponent of both equations?

$$\mathbf{r} = \frac{2(\mathbf{n} \cdot \mathbf{l})}{|\mathbf{n}||\mathbf{l}|}\mathbf{n} - \mathbf{l}$$

$$\mathbf{i}_s = \left(\frac{\mathbf{r} \cdot \mathbf{v}}{|\mathbf{r}||\mathbf{v}|}\right)^s * \mathbf{c}_s * \mathbf{l}_s$$

$$\mathbf{h} = \mathbf{l} + \mathbf{v}$$

$$\mathbf{i}_s = \left(\frac{\mathbf{n} \cdot \mathbf{h}}{|\mathbf{n}||\mathbf{h}|}\right)^s * \mathbf{c}_s * \mathbf{l}_s$$

Shininess

- What is the magic s in the exponent of both equations?
  - Controls the "size" of the specular highlight
  - As s increases, the highlight gets smaller
    - The dot-product is always less than 1.0, so raising it to some power makes it smaller faster.

$$\mathbf{r} = \frac{2(\mathbf{n} \cdot \mathbf{l})}{|\mathbf{n}||\mathbf{l}|}\mathbf{n} - \mathbf{l}$$

$$\mathbf{i}_s = \left(\frac{\mathbf{r} \cdot \mathbf{v}}{|\mathbf{r}||\mathbf{v}|}\right)^s * \mathbf{c}_s * \mathbf{l}_s$$

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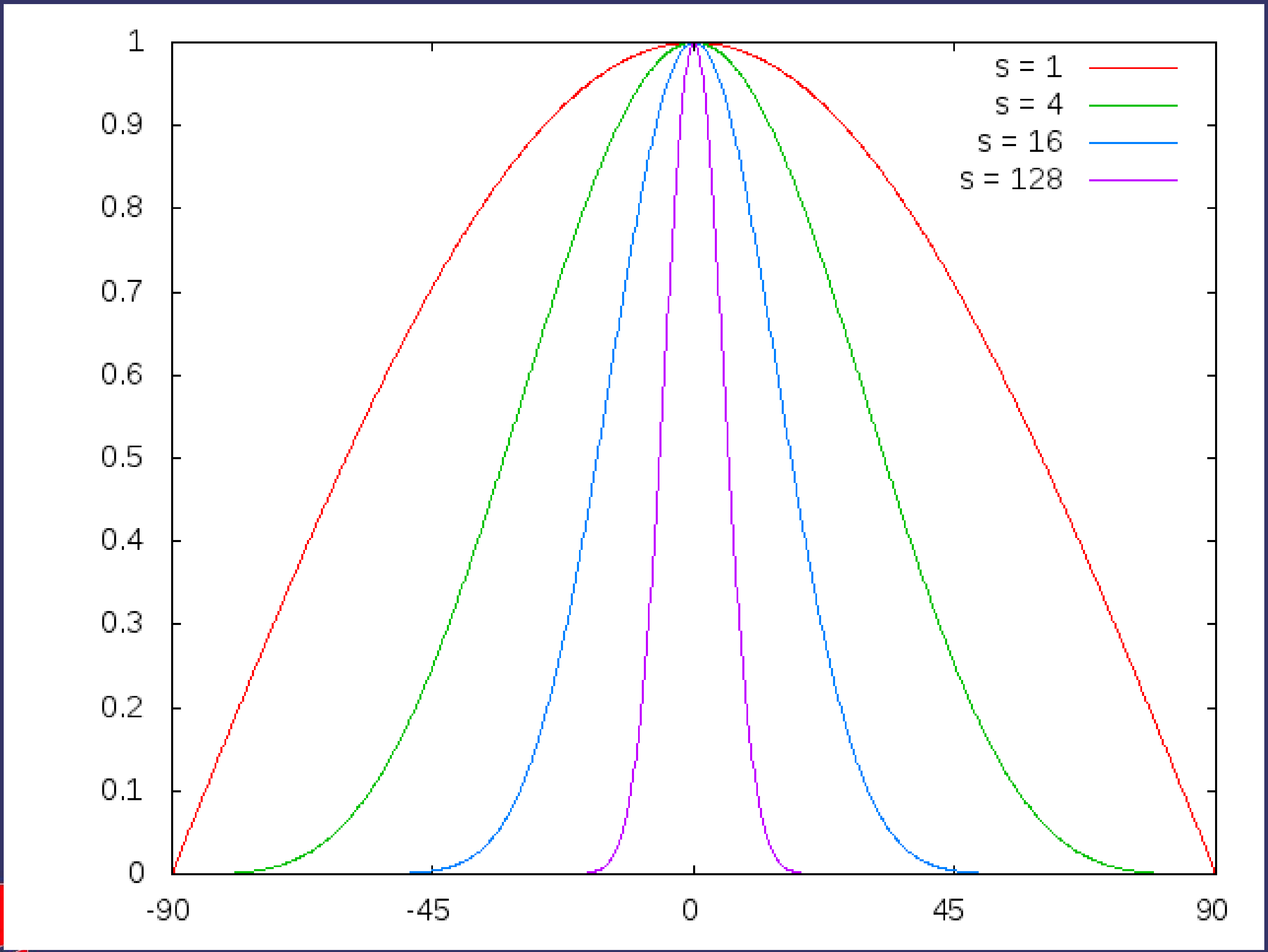
Shininess



Blinn-Phong vs. Phong

- The Blinn-Phong equation is an approximation of the Phong equation
  - Yes... an approximation of an approximation

$$\left(\mathbf{r}\cdot\mathbf{v}\right)^{s} \approx \left(\mathbf{n}\cdot\mathbf{h}\right)^{4s}$$

Ambient

- The lighting model so far is a purely *direct lighting* model
  - Most real world light bounces off of other objects, and is call *indirect lighting*
  - We can account for the background, indirect light by adding a simple ambient component

$$\mathbf{i}_a = \mathbf{c}_a * \mathbf{l}_a$$

- *This is the biggest hack of all!*

Shading Models

- We know how to calculate lighting values, but the question remains: how often do we calculate it?

Flat Shading

- Simplest answer: calculate lighting once per polygon
  - Fast!
  - Depending on the circumstances, the quality may be good enough...but usually not

Gouraud Shading

- Calculate lighting once per vertex, interpolate colors across polygon
  - A little slower: more math, have to do interpolation

Gouraud Shading

- Calculate lighting once per vertex, interpolate colors across polygon
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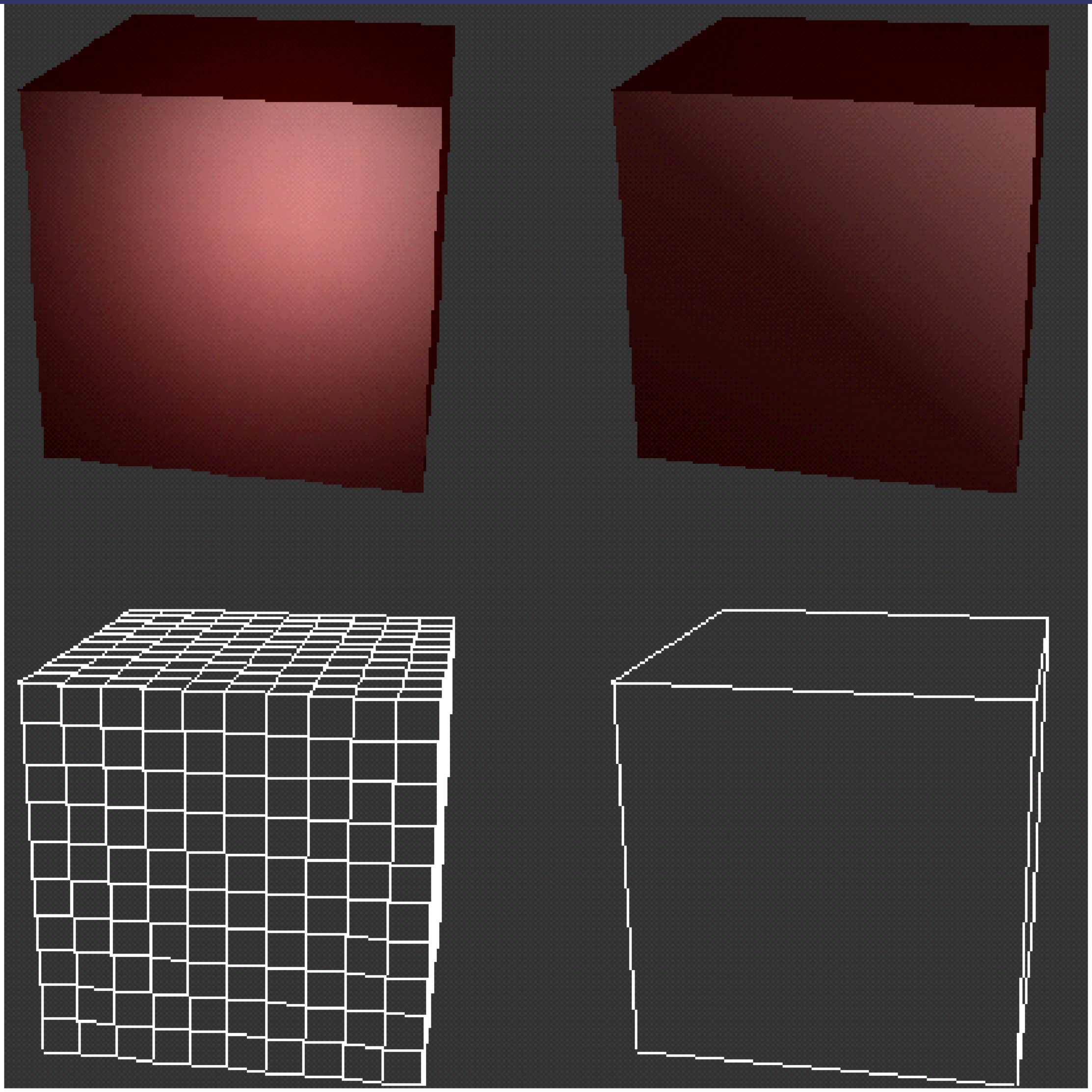
For all intents and purposes, this is free.

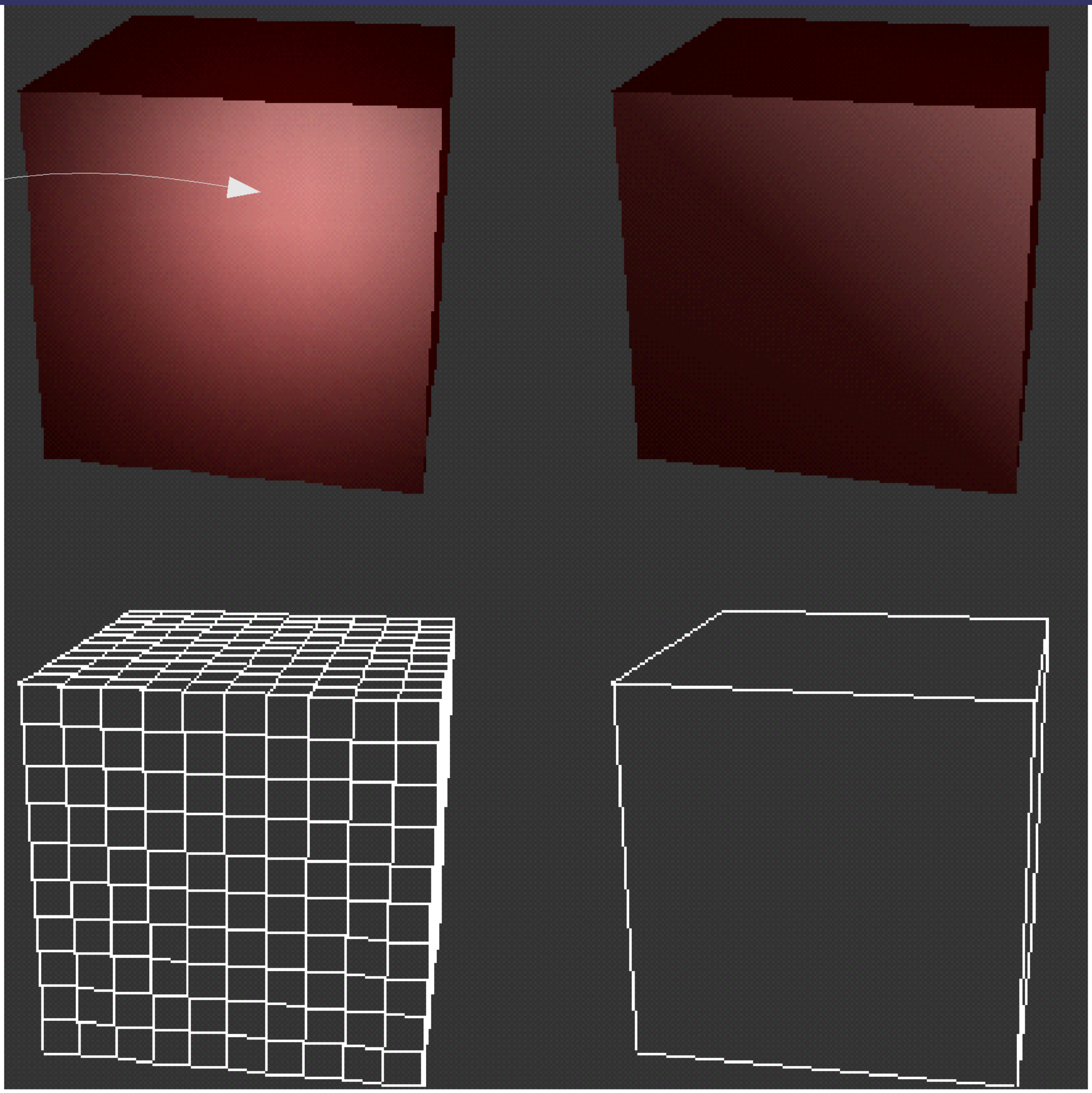
Gouraud Shading

- Calculate lighting once per vertex, interpolate colors across polygon
  - A little slower: more math, have to do interpolation
  - Looks better
  - Works well for diffuse, but works poorly for specular

Gouraud Shading



Gouraud Shading



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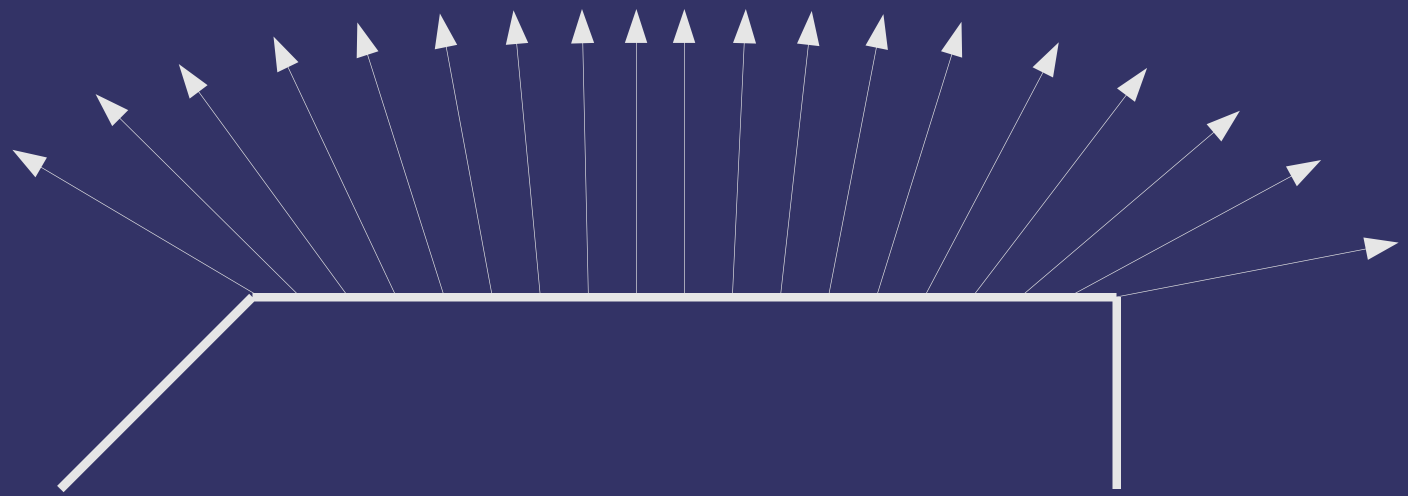
Phong Shading

- Next logical step: interpolate lighting parameters, calculate lighting per pixel
  - Looks much better...doesn't miss the specular high-light!
  - Much more expensive to calculate
    - Has really only been practical for real-time rendering for the last couple years
    - Not only requires the lighting to be recalculated per pixel, but interpolated vectors may need to be re-normalized per pixel

Phong Shading



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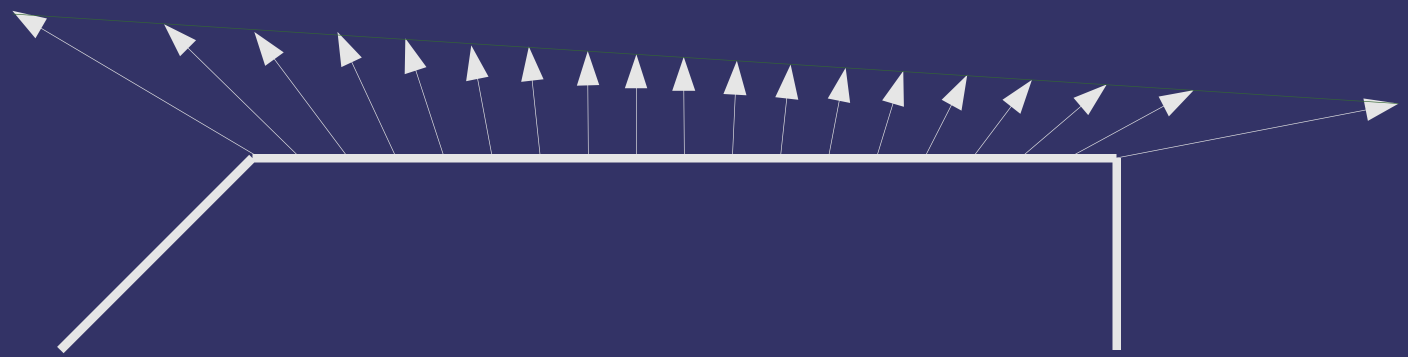
Phong Shading



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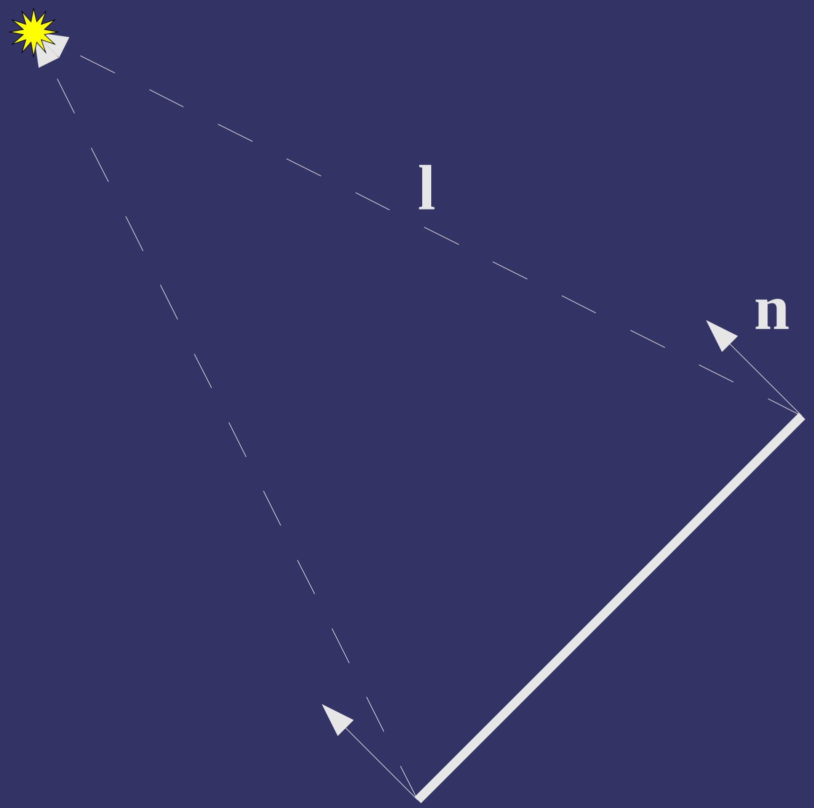
Types of Lights

- Several common types of lights used in graphics:
  - Point light
  - Directional light
    - Also called infinite light
  - Area lights
  - Spot lights

Point Lights

- Calculate the **l** vector by subtracting the vertex position from the light position and normalize the result



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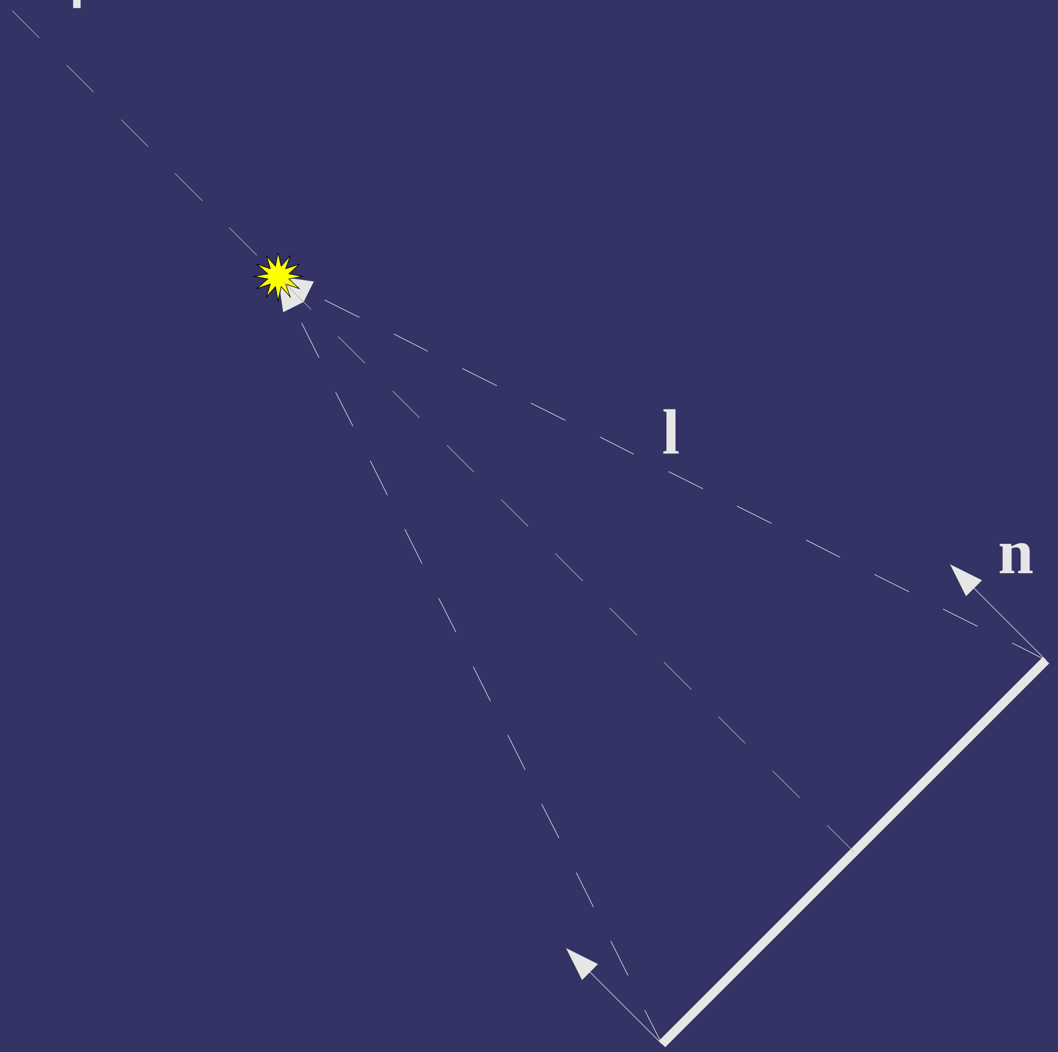

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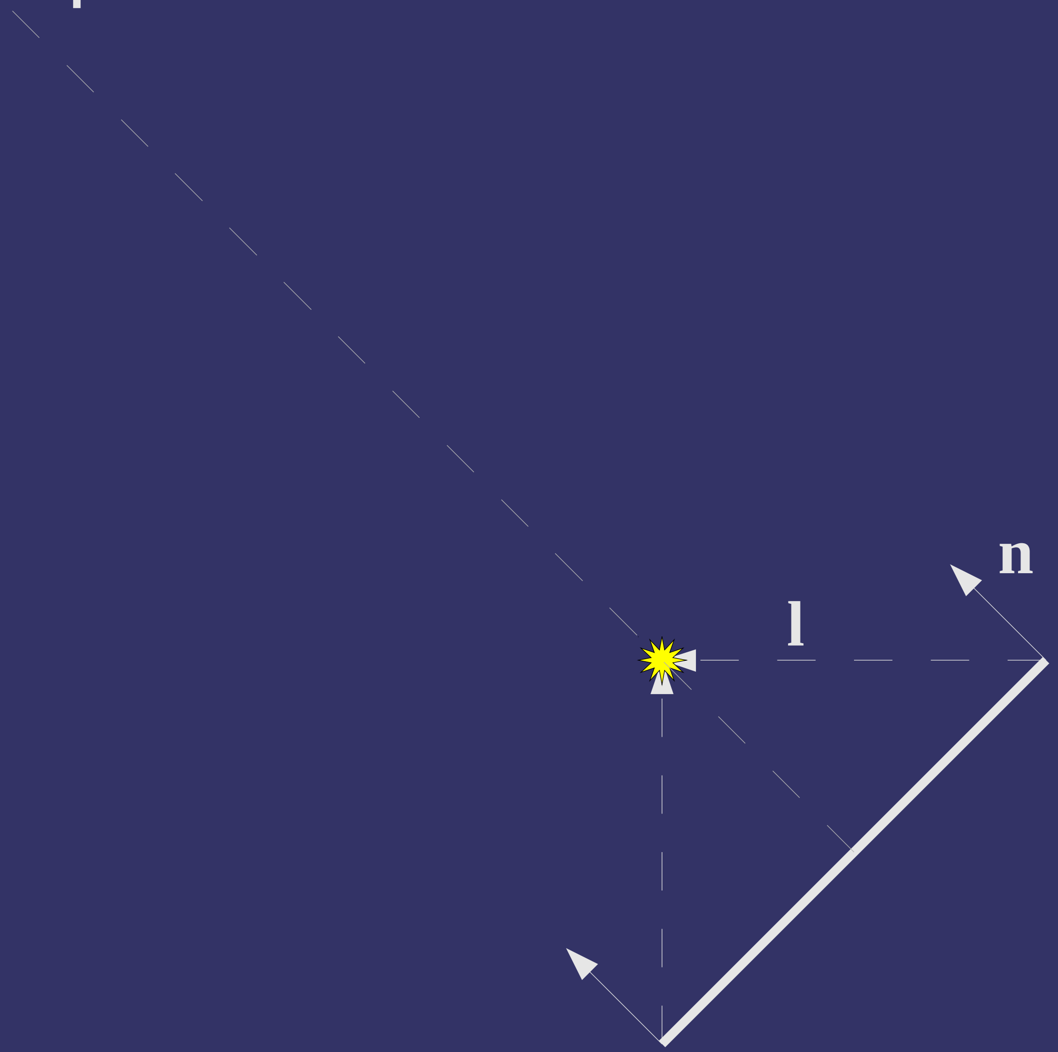

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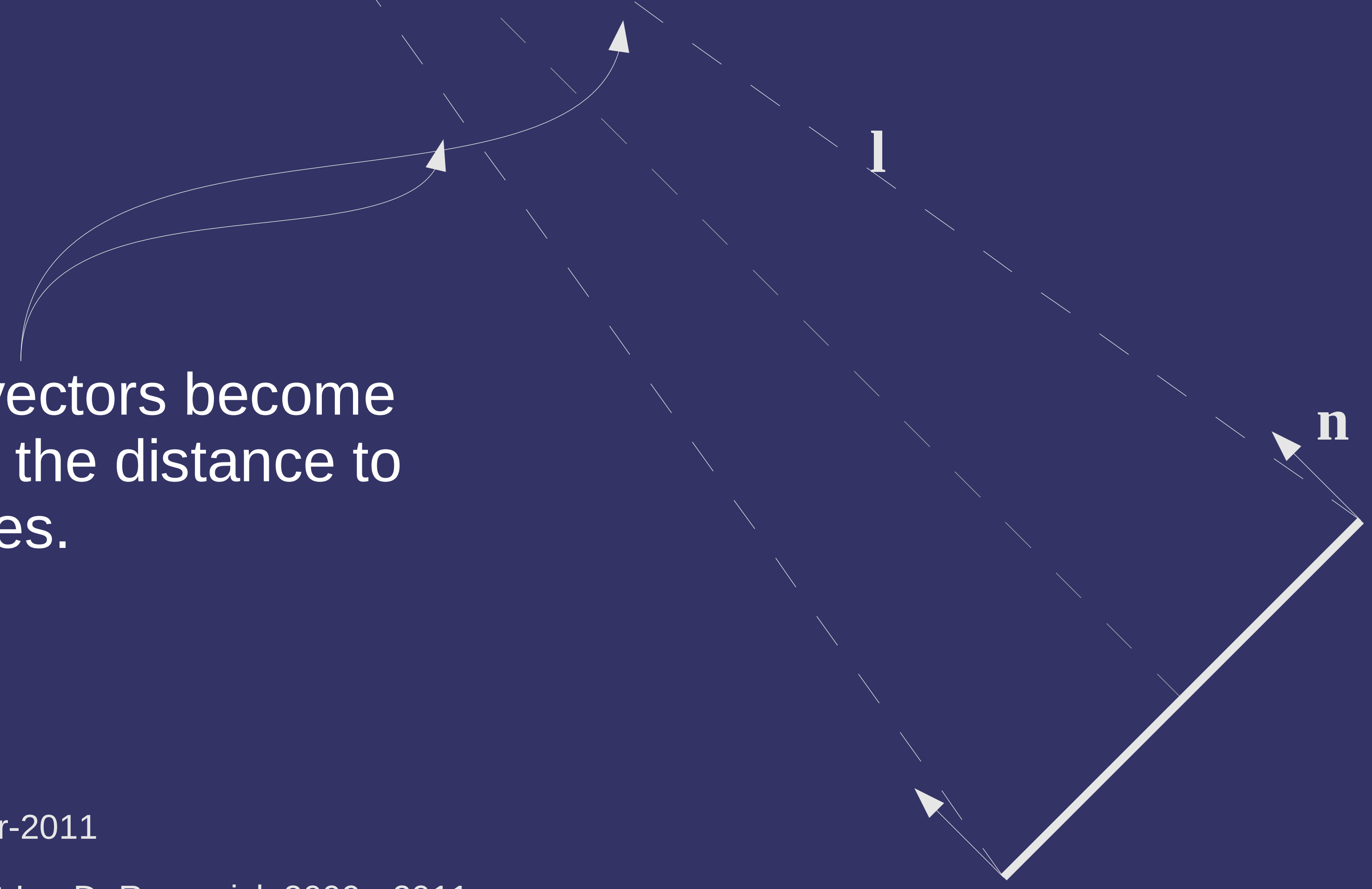


Note how the **l** vectors become more parallel as the distance to the light increases.

Directional Lights

- For lights at infinity, all **l** vectors are parallel
  - Simplify the math, treat the light as *just* a direction
  - Direction doesn't change → don't to interpolate it!
    - Still have to transform it into the space where lighting is calculated

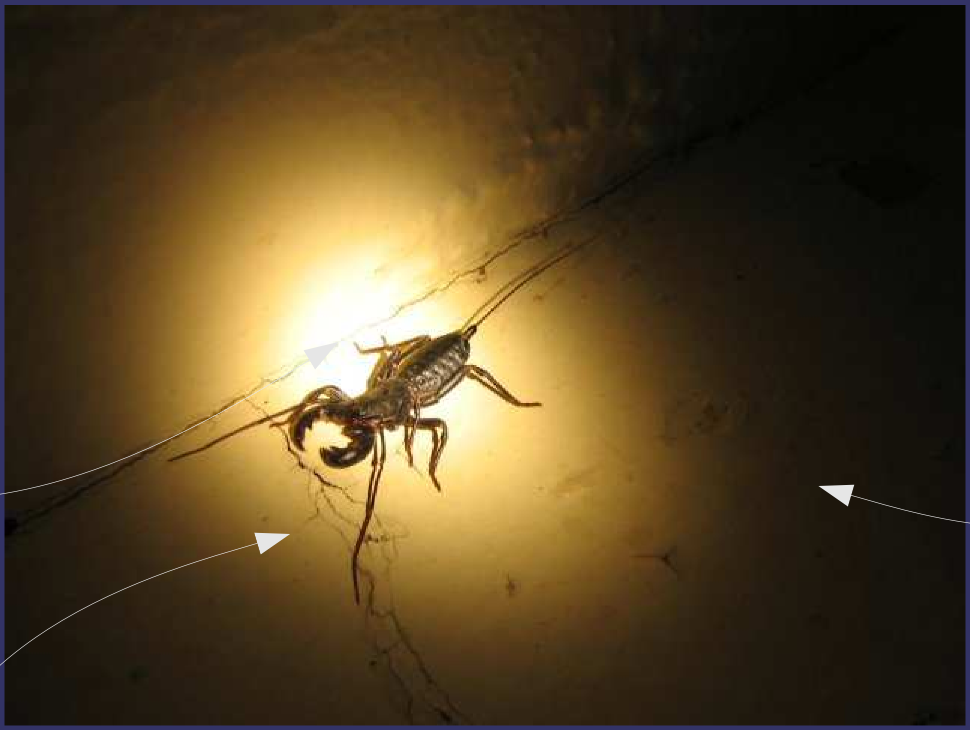
Area Lights

- Both models treat lights as infinitesimal points
  - All real lights have some surface area
  - Lights with larger surface areas are considered "softer"
    - This results in shadows with smoother boundaries
    - This is why we have frosted light bulbs and lamp shades instead of bare, clear glass bulbs
  - Techniques exist for handling these sorts of lights, but they are expensive and (currently) impractical for most real-time use
    - We'll discuss this more next term

Spot Light

- Most lights don't emit light in all directions
  - Some range over which the light intensity is 100%
  - Some range over which the light intensity gradually decreases
    - This range may be zero
  - Remaining range where no light is emitted

Spot Light



Full intensity light

No light

Partial intensity light

Image, by *satanoid*, from http://www.everystockphoto.com/photo.php?imageId=673587

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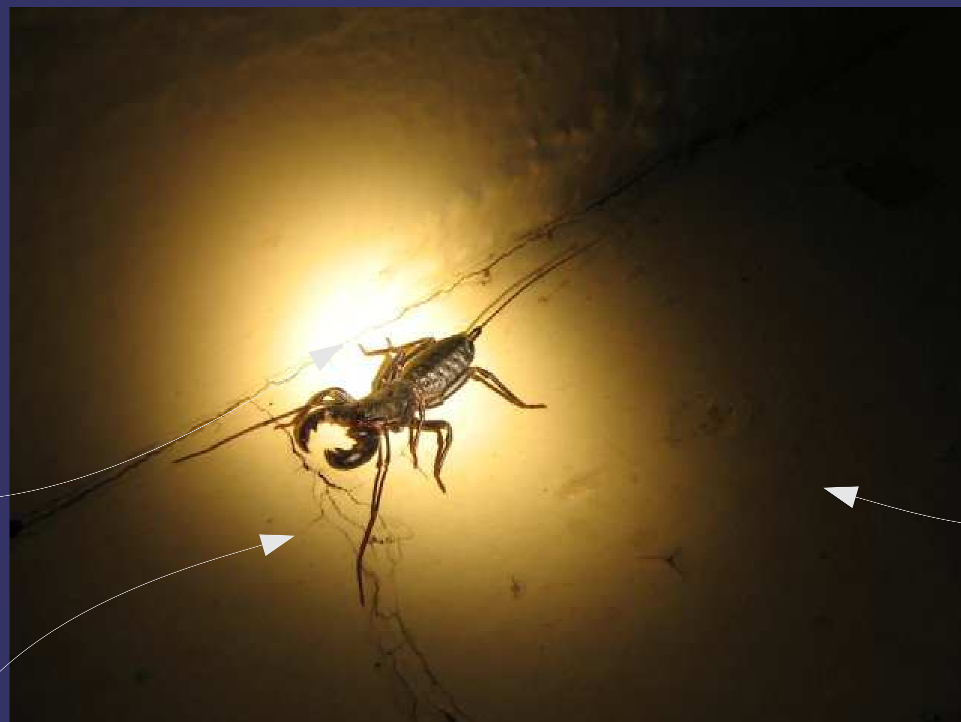
Spot Light



Full intensity light

~~No light~~
Ambient light

Partial intensity light

Image, by *satanoid*, from http://www.everystockphoto.com/photo.php?imageId=673587

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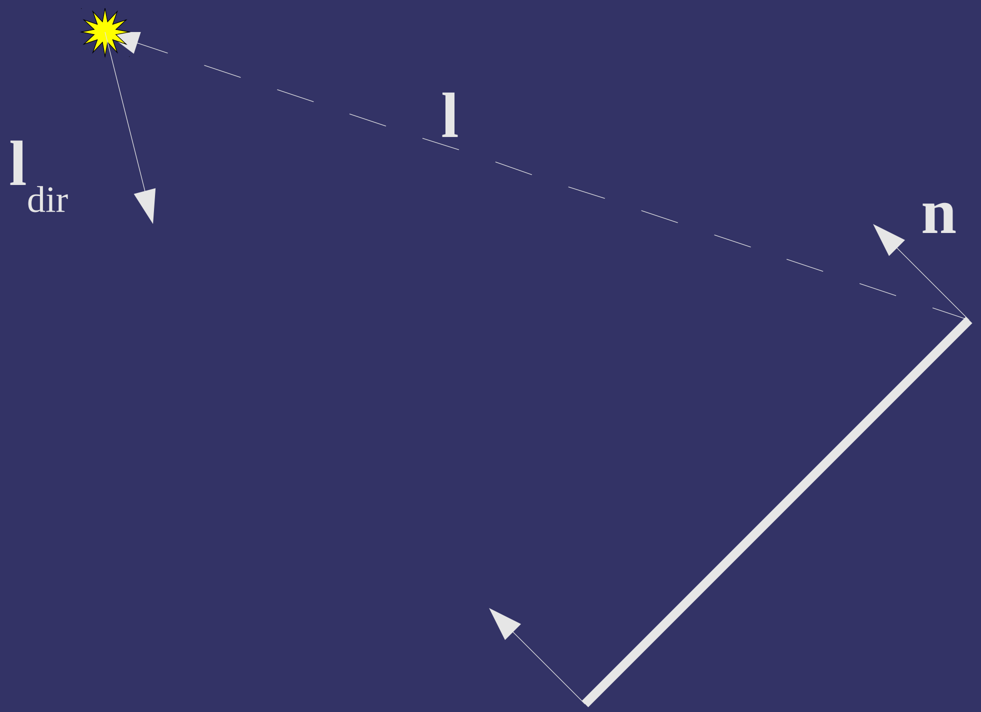
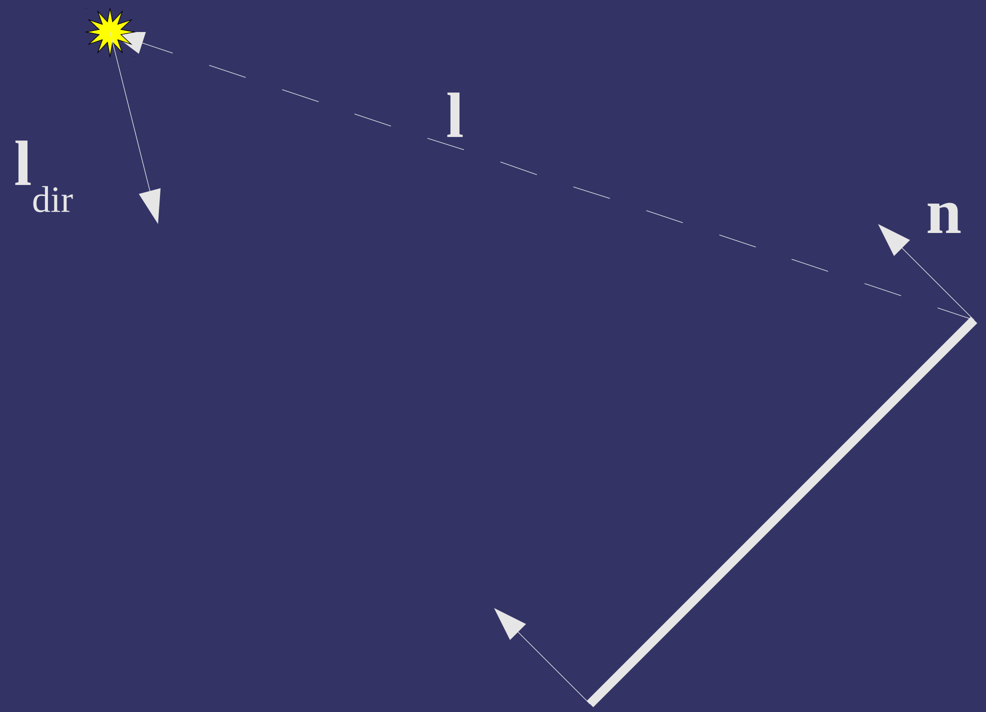
Spot Light

- Need additional light parameters:
  - $\mathbf{l}_{dir}$ – direction the light is pointing
  - l_{cut} – Absolute cut-off angle
  - l_{exp} – Exponent for cut-off equation



Spot Light

$$\mathbf{i} = \begin{cases} \left(\mathbf{l}_{\mathrm{dir}} \cdot -\mathbf{l}\right)^{l_{\exp}} * \mathbf{i}_{\mathrm{L}} & \text{if } \left(\mathbf{l}_{\mathrm{dir}} \cdot -\mathbf{l}\right) > \cos\left(l_{\mathrm{cut}}\right) \\ 0 & \text{otherwise} \end{cases}$$



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Distance Attenuation

- The farther a light is from an object, the less light gets to that object
  - Three separate factors control the attenuation
  - k_c – constant attenuation factor
  - k_l – Linear attenuation factor
  - k_q – Quadratic attenuation factor

$$d = |\mathbf{l}|$$

$$a = \frac{1}{k_c + k_l d + k_q d^2}$$

Next week...

- Bounding volumes
  - Bounding spheres
  - Axis-aligned bounding boxes (AABBs)
  - Oriented bounding boxes (OBBs)
  - Heirarchies of BVs
- More occlusion
  - Hierarchical frustum culling

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