Lighting and Shading

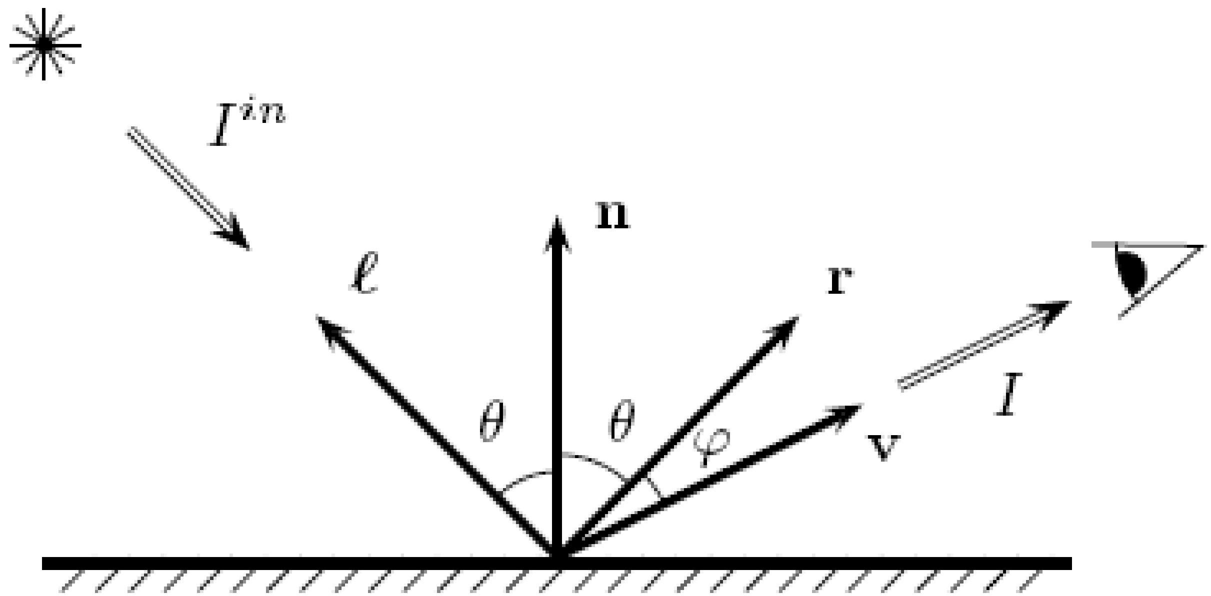
Today: Local Illumination

Solving the rendering equation is too expensive

First do local illumination

Then “hack in” reflections and shadows

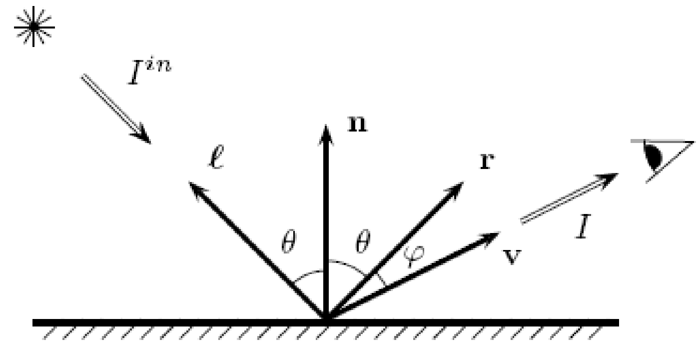
Local Shading: Notation



I^{in}, I light intensity in, light intensity out

$\hat{l}, \hat{n}, \hat{v}, \hat{r}$ vector pointing to: light, normal direction, eye, reflection direction

Ambient Term

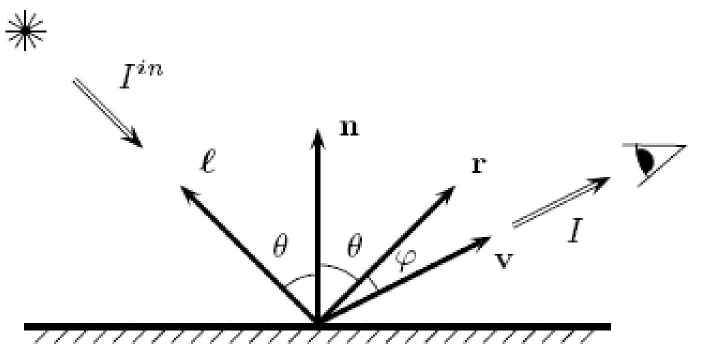


Ignore camera and light direction completely

$$I_a = k_a I^{in}$$

material constant

Ambient Term



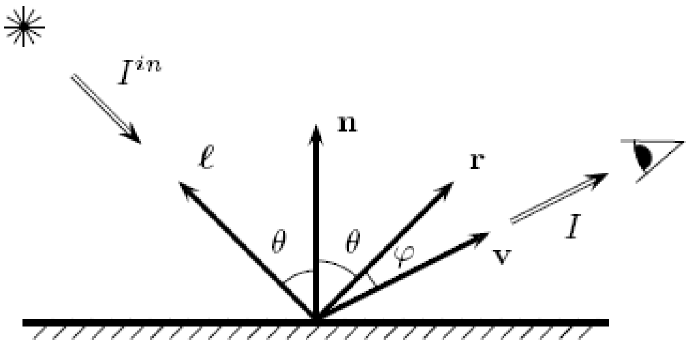
Ignore camera and light direction completely

$$I_a = k_a I^{in}$$

one eq. per color channel

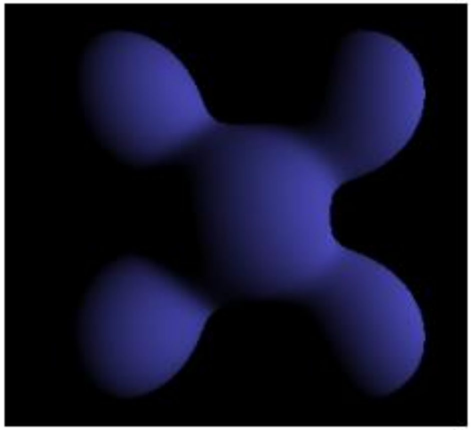
material constant

Diffuse Term



Lambertian surface – **constant** BRDF

$$I_d = k_d \max(\hat{l} \cdot \hat{n}, 0) I^{in}$$



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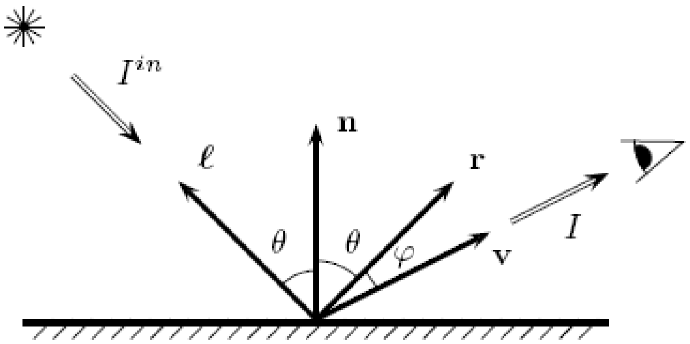
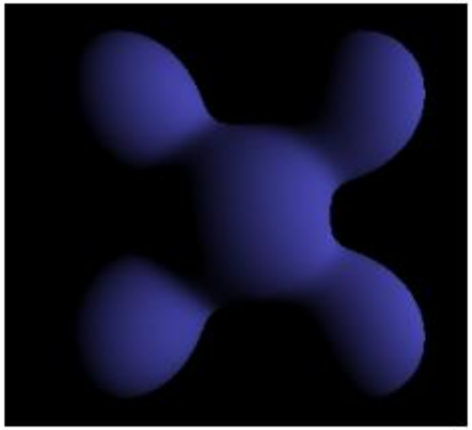


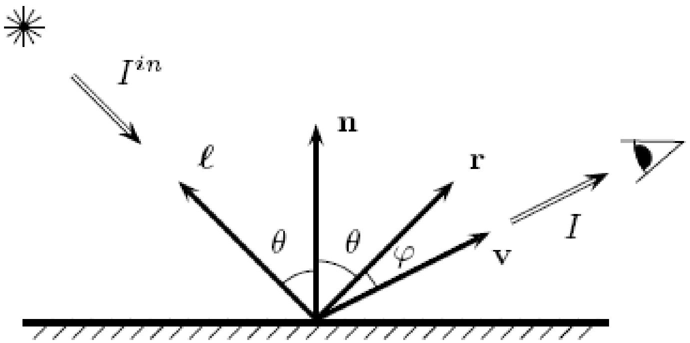
Lambertian surface – **constant** BRDF

$$I_d = k_d \max(\hat{l} \cdot \hat{n}, 0) I^{in}$$

ignore back faces

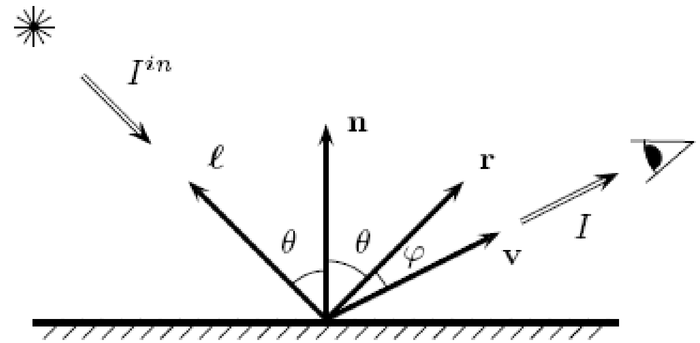


Specular Term



Perfect specular surface doesn't work

Specular Term

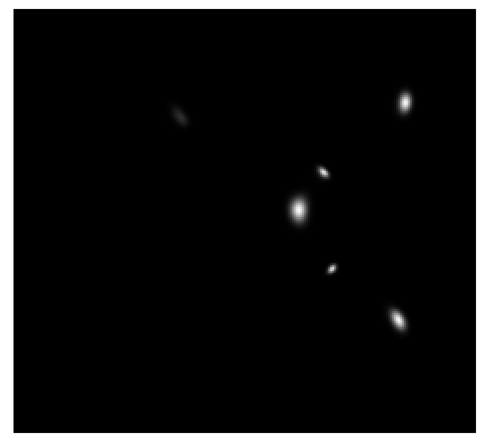


Perfect specular surface doesn't work

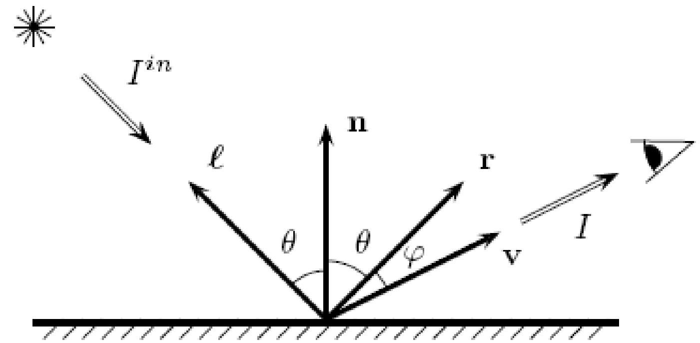
Phong model:

$$I_s = k_s \max(\hat{v} \cdot \hat{r}, 0)^{\alpha} I^{in}$$

specularity coefficient



Specular Term



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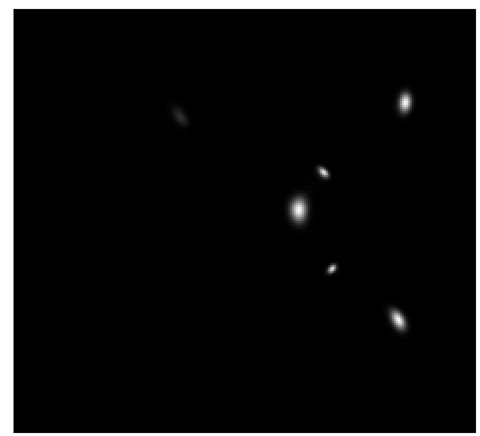
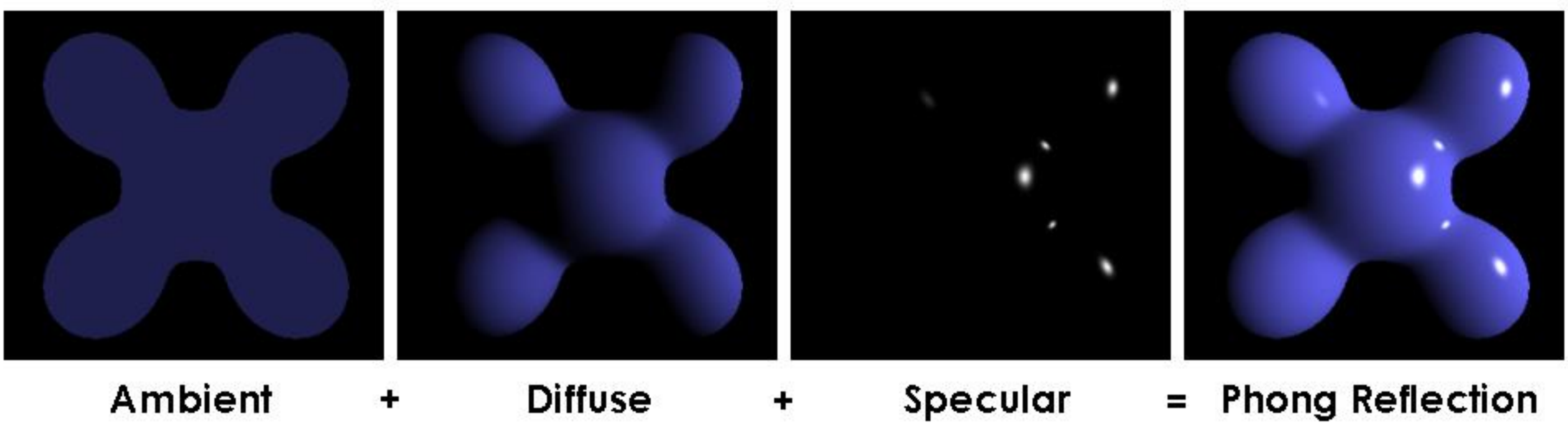


Looks like “highlight” that moves with light & eye

Putting It Together

$$I = \left[k_a + k_d \max(\hat{l} \cdot \hat{n}) + k_s \max(\hat{v} \cdot \hat{r}, 0)^{\alpha}\right] I^{in}$$



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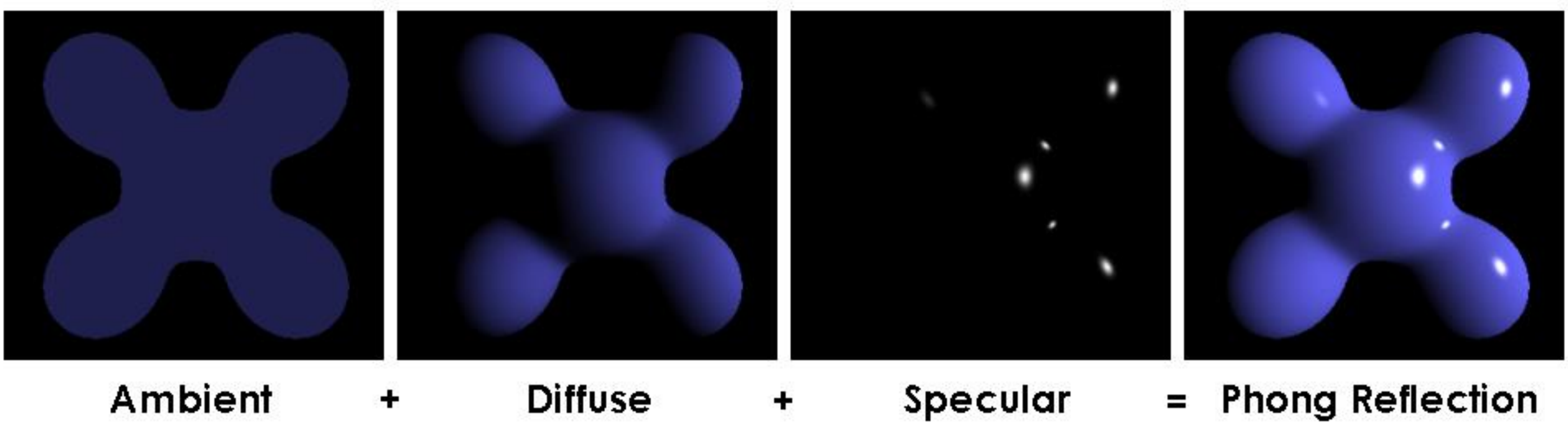
typically: $k_a = 0; k_s = 1$



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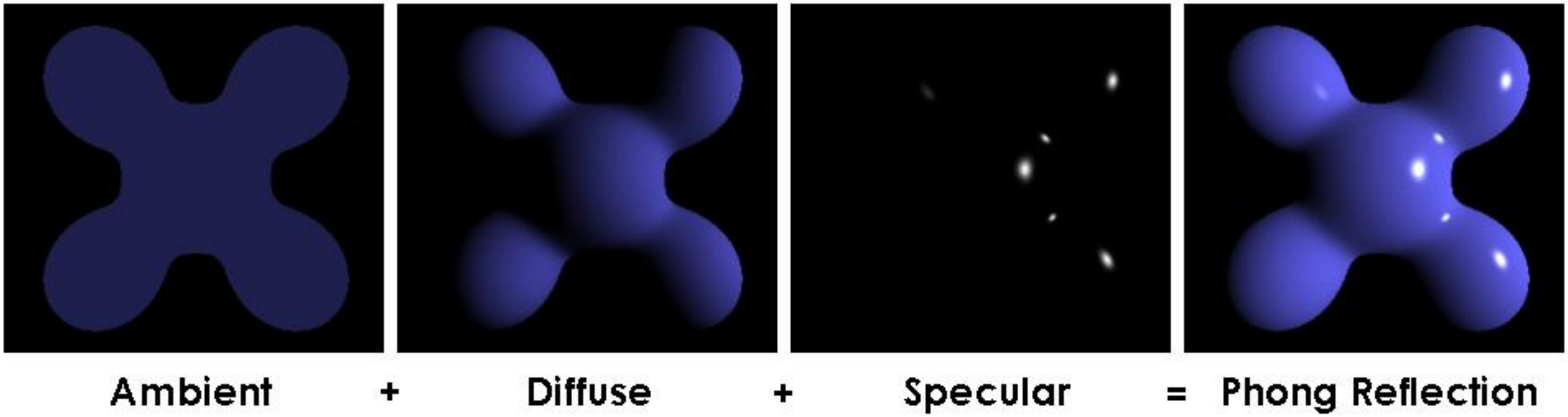
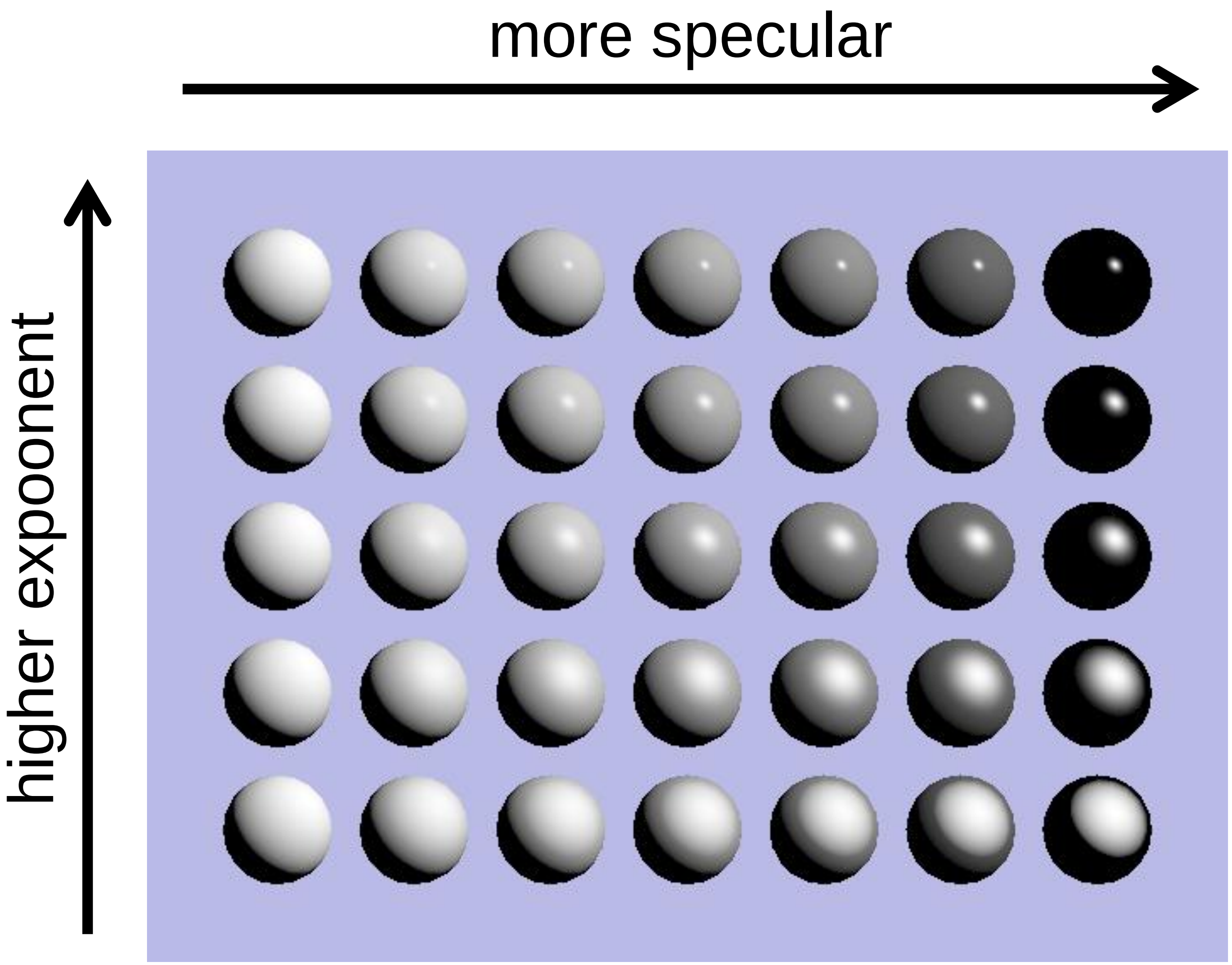
three copies of equation, one per color channel

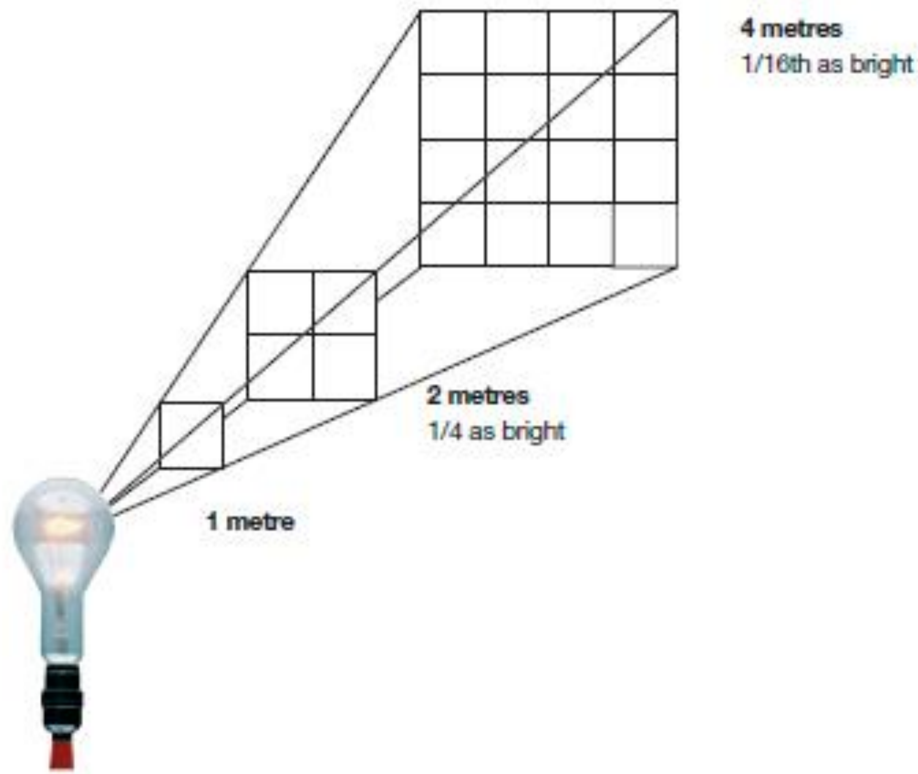


Specularity Coefficient



Light Attenuation

Real light attenuation: inverse square law

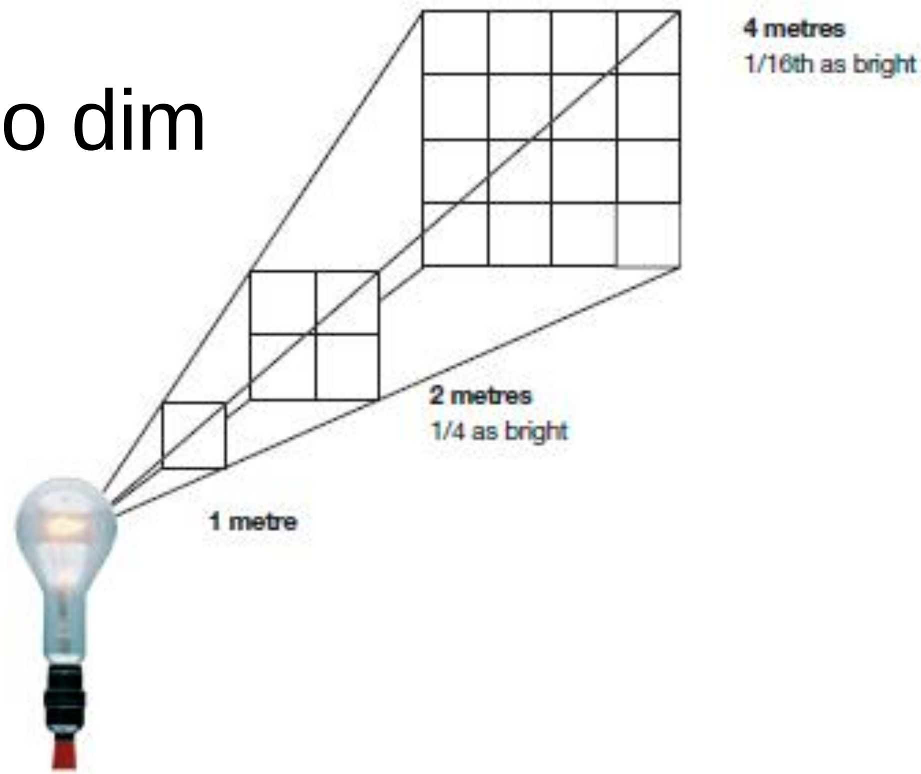


Light Attenuation

Real light attenuation: inverse square law

Tends to look bad: too dim
or washed out

So, we cheat



Light Attenuation

$$I^{atten} = \frac{1}{c_0 + c_1 d + c_2 d^2} I$$

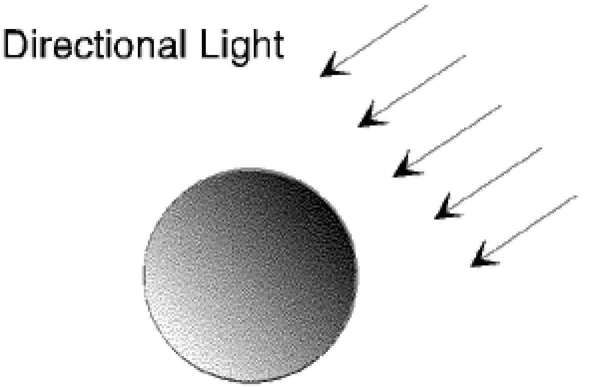
d is light-to-point distance

Can tweak constant & linear term to taste

Directional Light

“Light at infinity”

- Sun



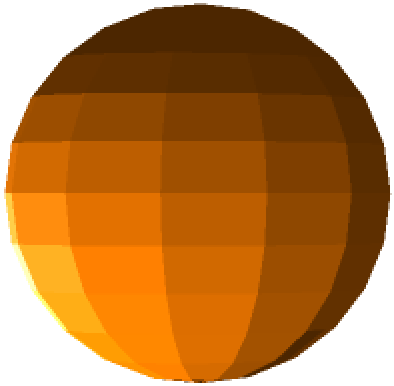
All light rays parallel

Obviously, no attenuation

Dealing with Discrete Geometry

Flat shading: use normal per face

Very obvious discontinuities
at edges

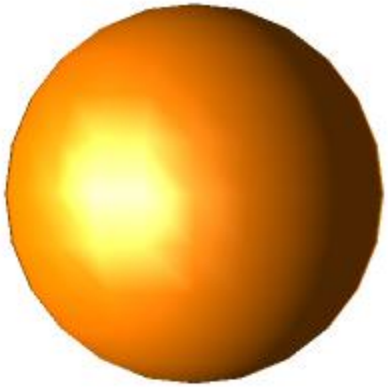


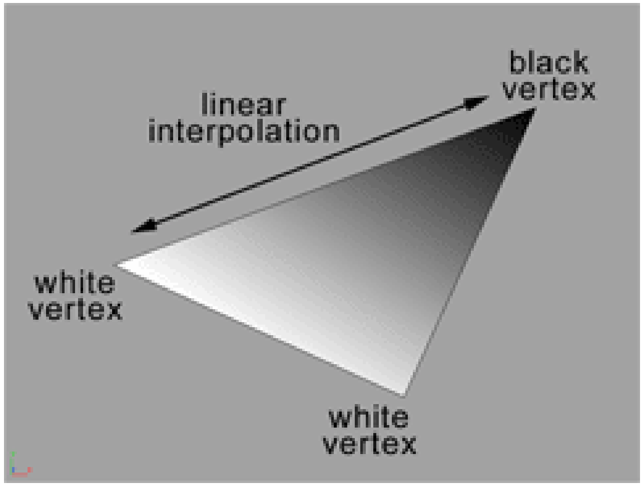
Only used for stylized “chunky” effect

Gouraud Interpolation

First, compute color at vertices

Linearly interpolate color
over face





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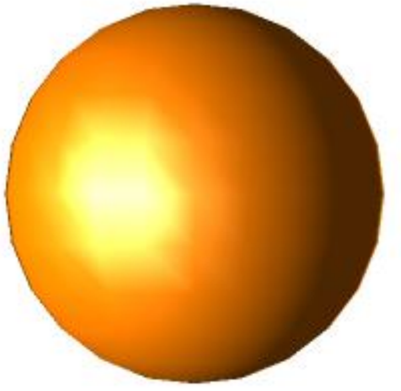


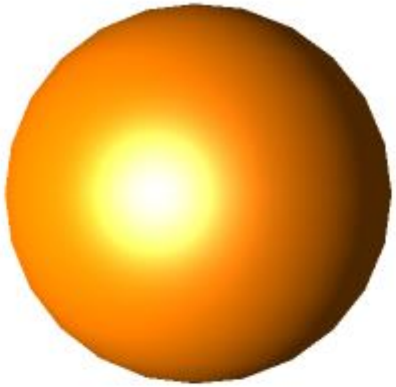
Color now continuous, but still obvious
artifacts (nobody uses this anymore)

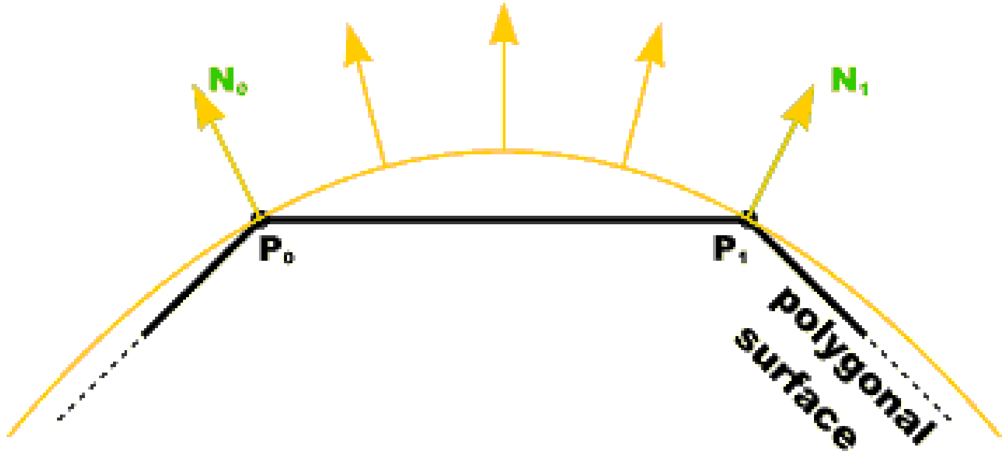
Phong Interpolation

First, linearly interpolate normals

Next, renormalize normals (**important**)

Then, compute color per pixel





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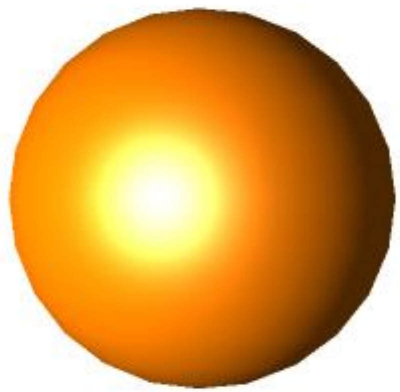


Because of all of the normalizations, used to be considered decadent;
now **the** standard local shading scheme

Local vs Global Illumination

Local:

- shade each object based only on itself, the eye, and the light sources

Global:

- take all other objects in scene into account also
- BRDFs and the rendering equation

Local vs Global Illumination

Grey Area:

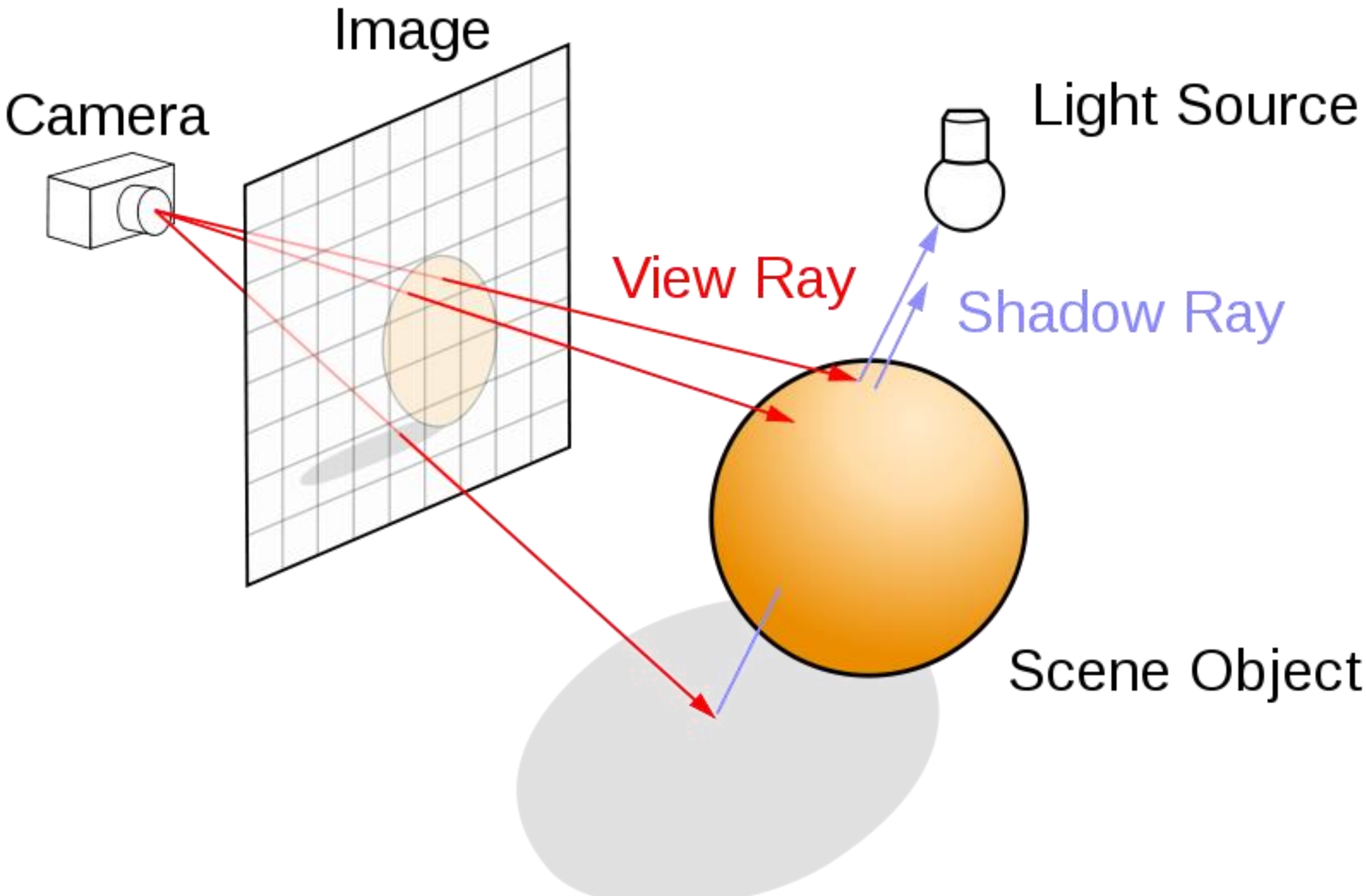
- take other objects into account, without full global illumination
- adds realism without being too slow

Local vs Global Illumination

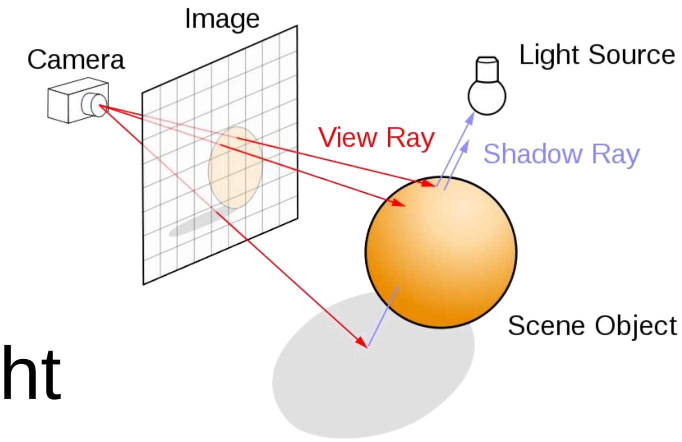
Grey Area:

- take other objects into account, without full global illumination
- adds realism without being too slow
- common techniques exist for
  - shadows
  - reflections
  - refractions

Shooting Shadow Rays



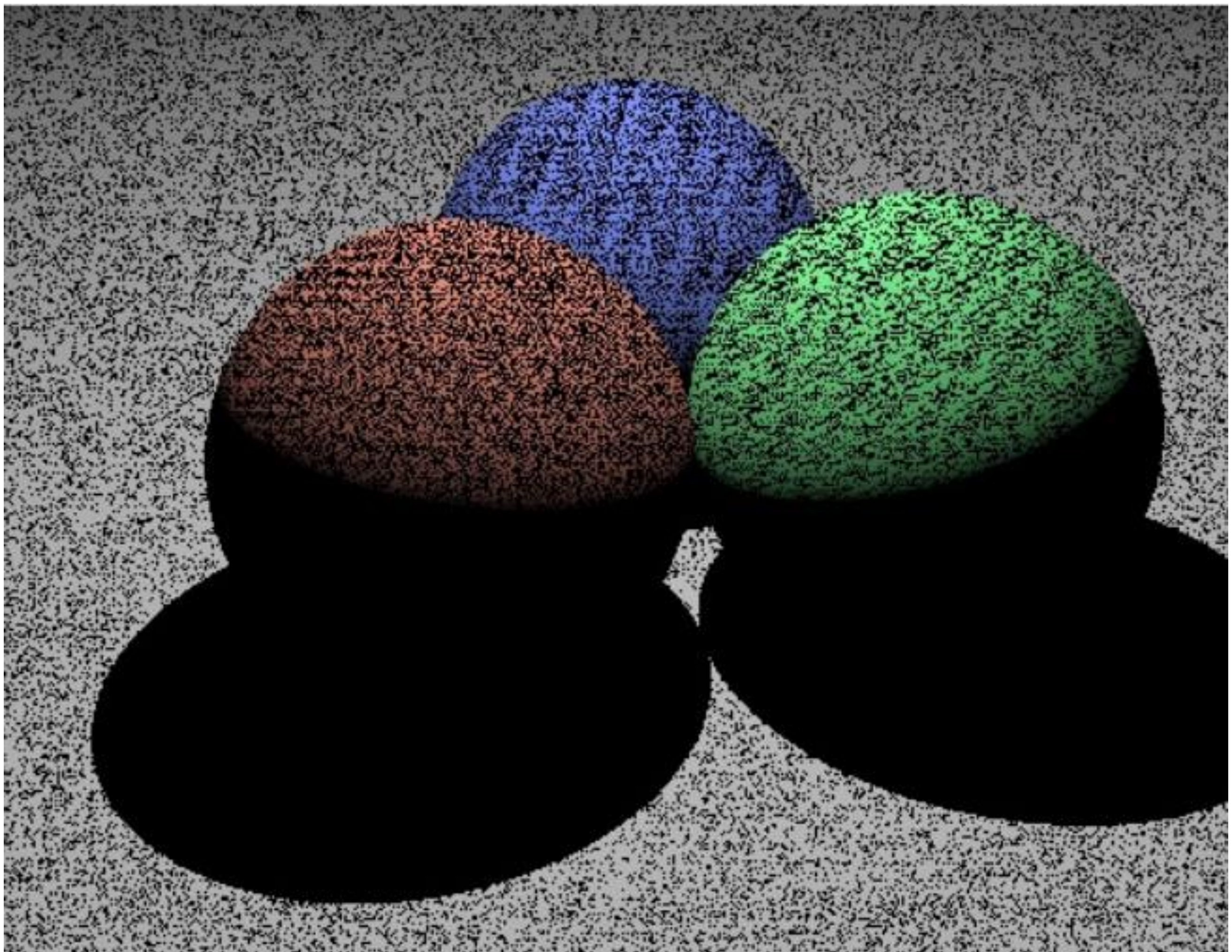
Shooting Shadow Rays



For each intersection pt:

- for each light:
    - shoot ray from point to light
    - if it hits an object:
        - do nothing (shadow)
    - else add shading contribution

Classic Bug



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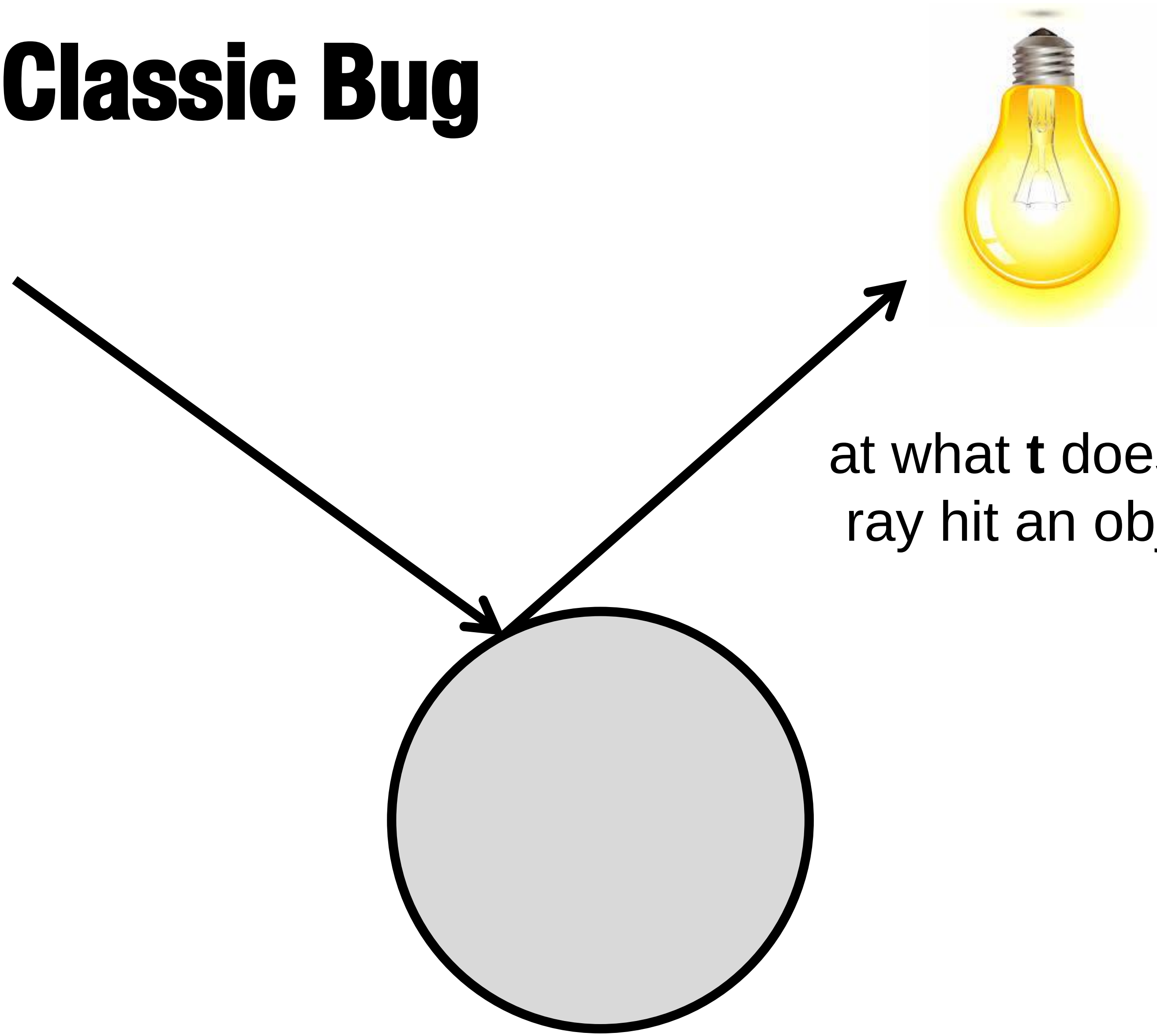
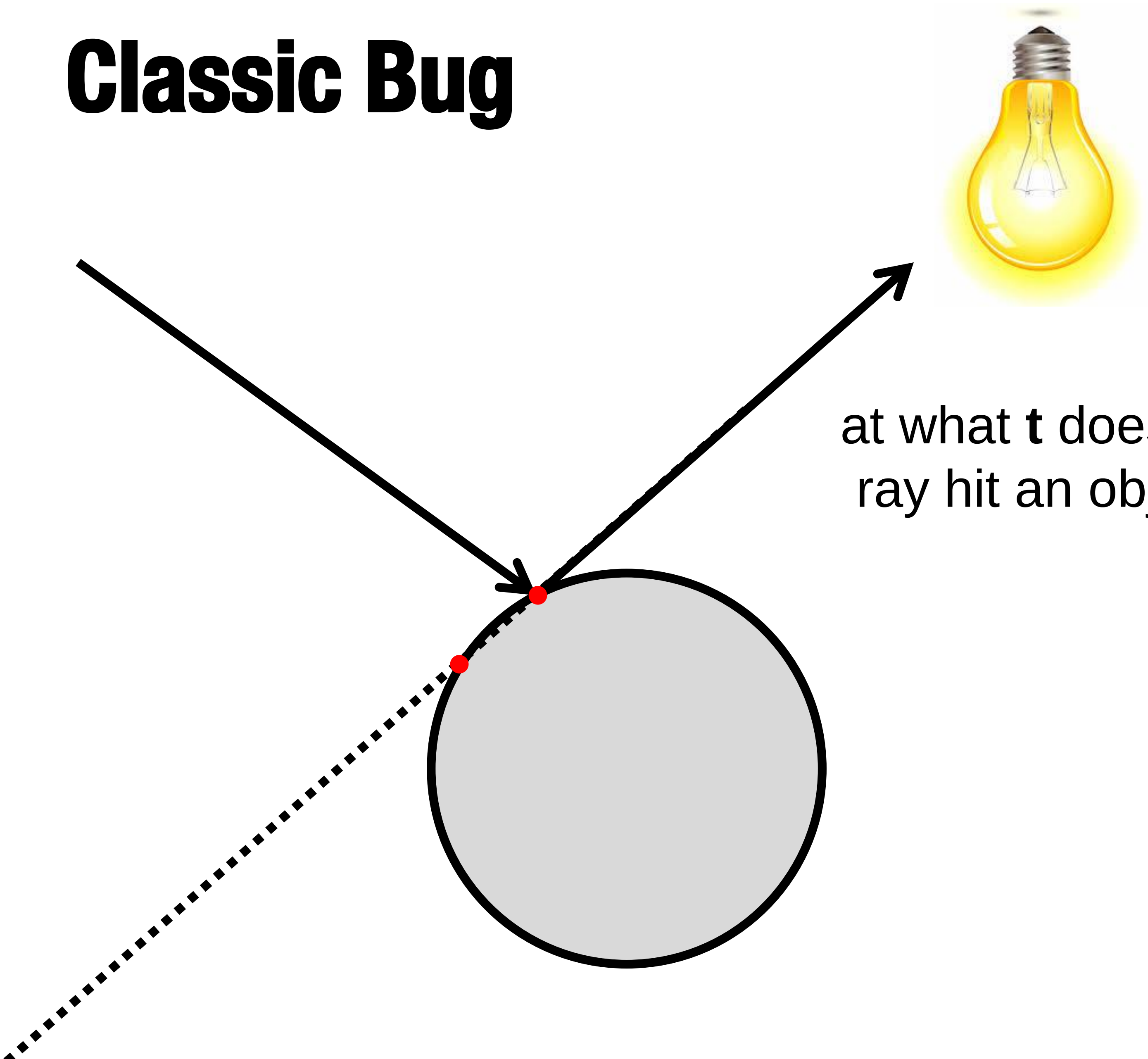


at what **t** does the ray hit an object?

Classic Bug



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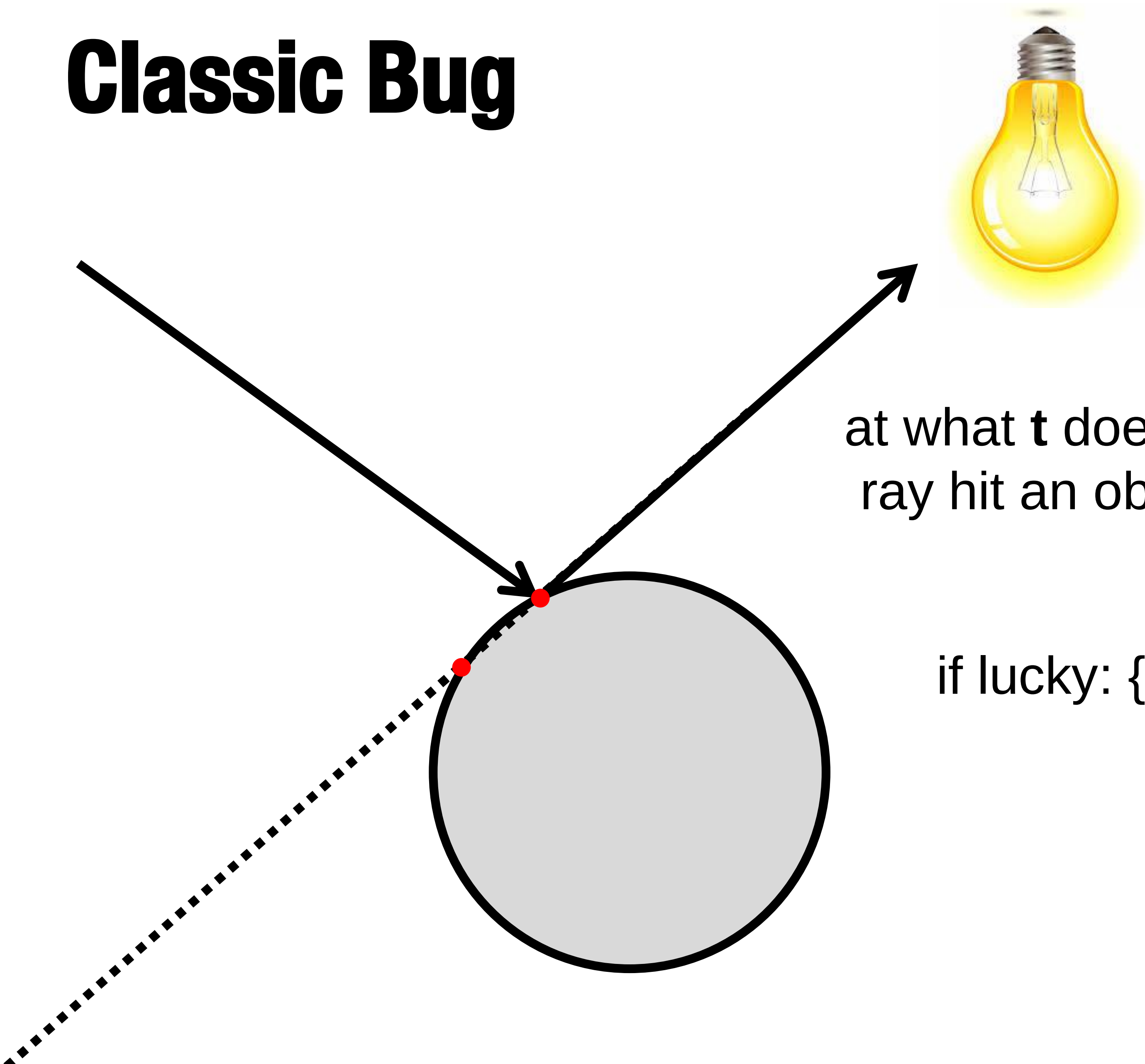

at what **t** does the ray hit an object?

if lucky: {-1.2, 0.0}

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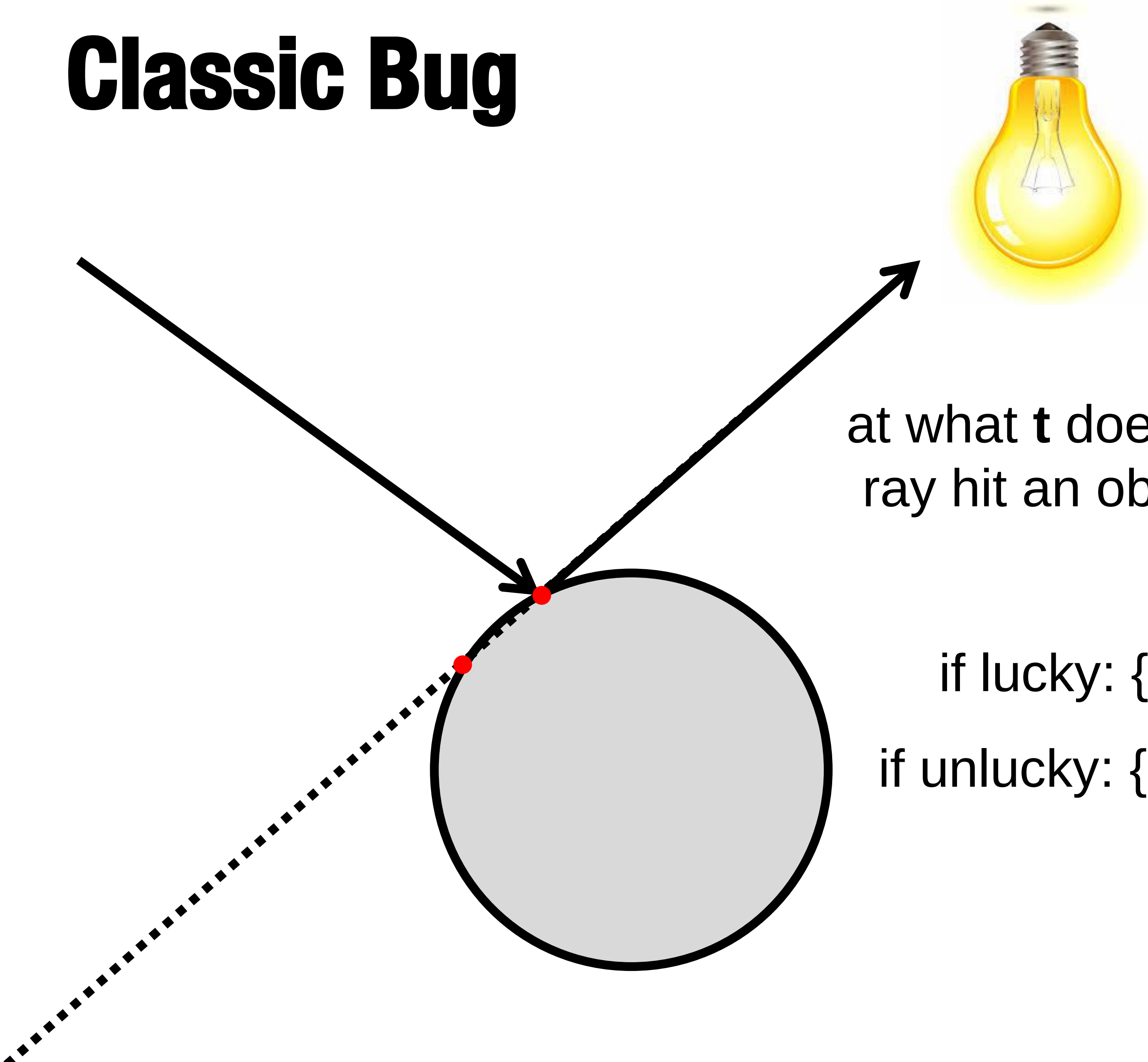

at what **t** does the ray hit an object?

if lucky: {-1.2, 0.0}

if unlucky: {-1.2, 1e-12}

Ignore t Near Zero?

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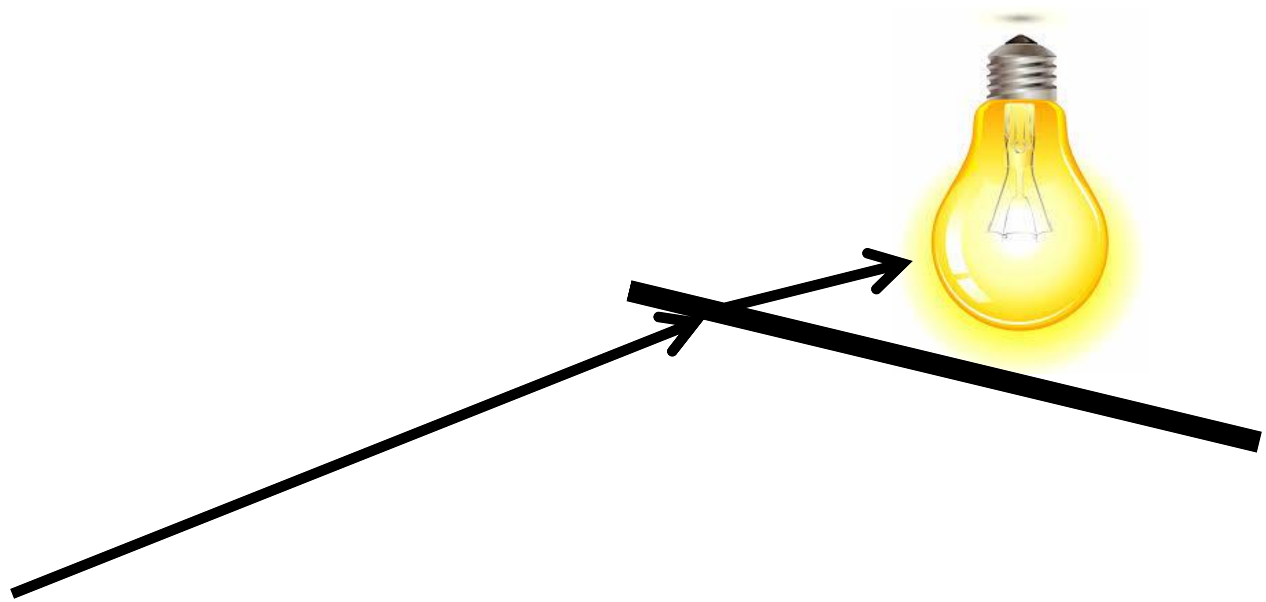

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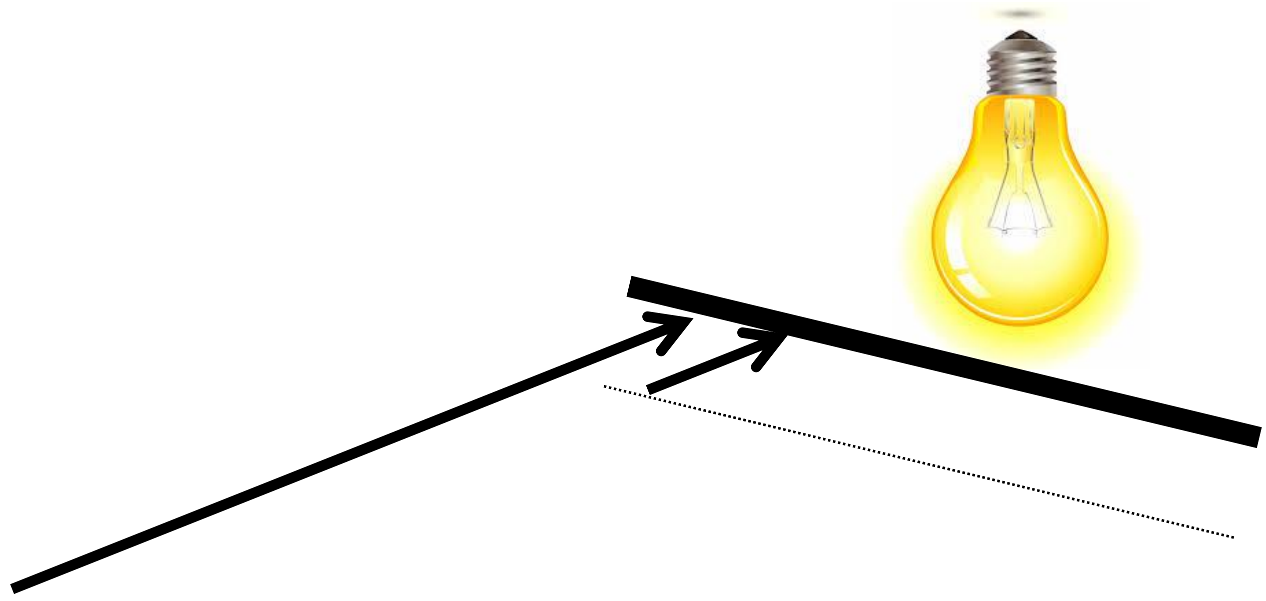


Fix: move slightly in normal direction (or backward ray direction) before shooting shadow ray

Hard Shadows

real-world doesn't look like this

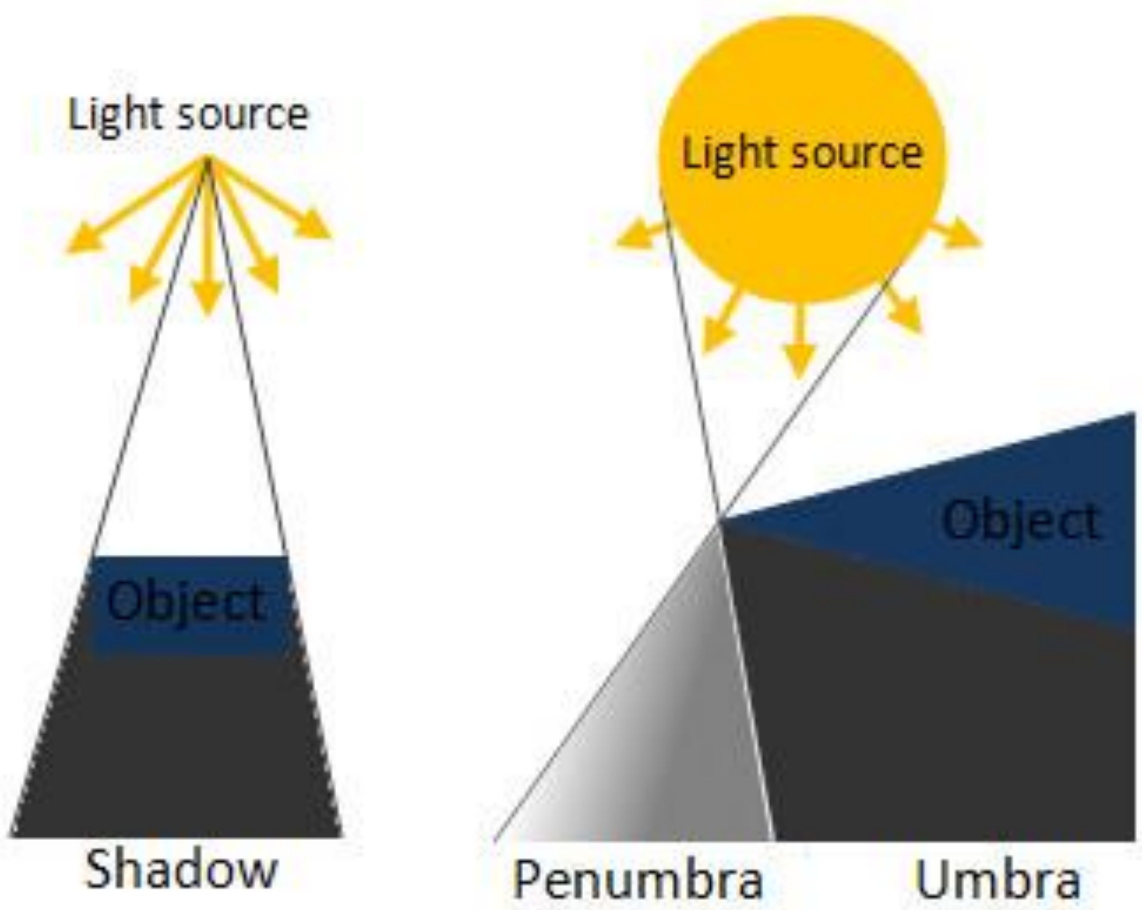
Hard Shadows

real-world doesn't
look like this

shadows usually
soft

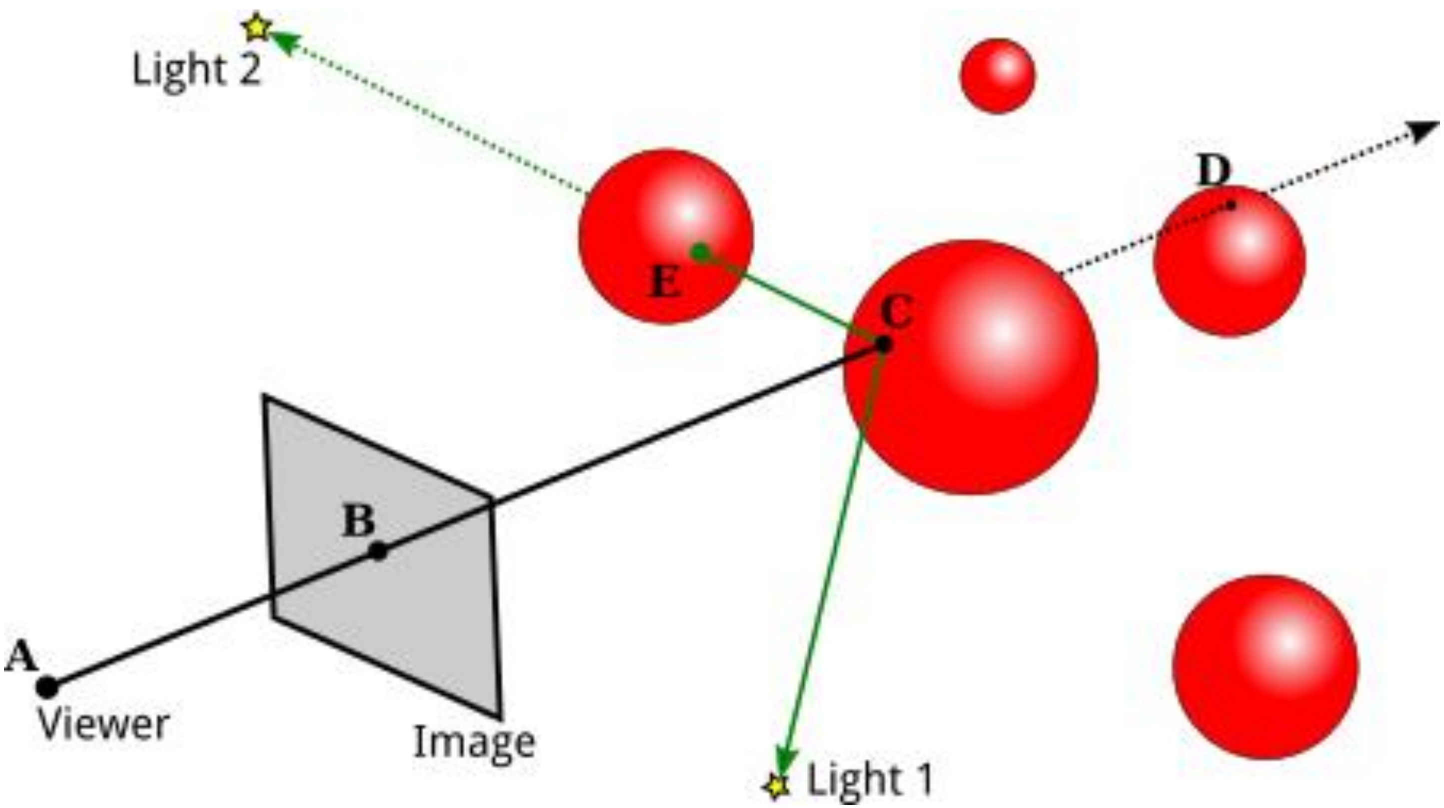
why?

Soft Shadows



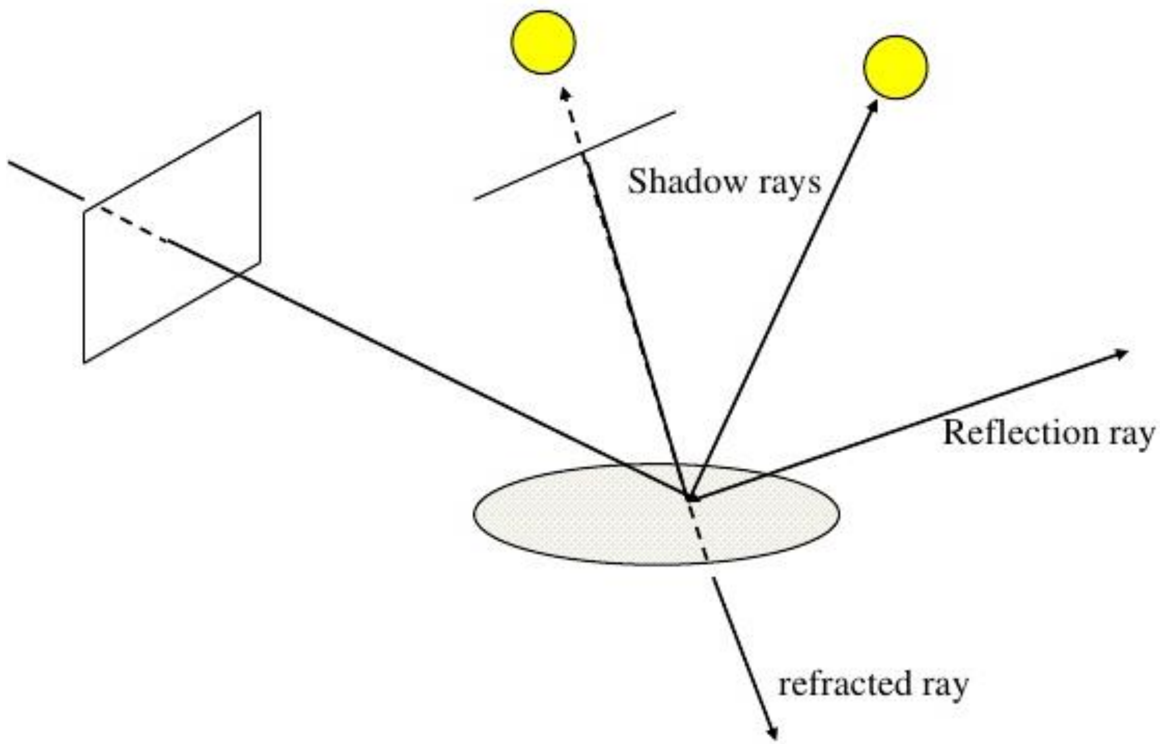
Other Secondary Rays

Translucent objects



Other Secondary Rays

Reflection & refraction



Reflection

Purely specular (mirrored) surface

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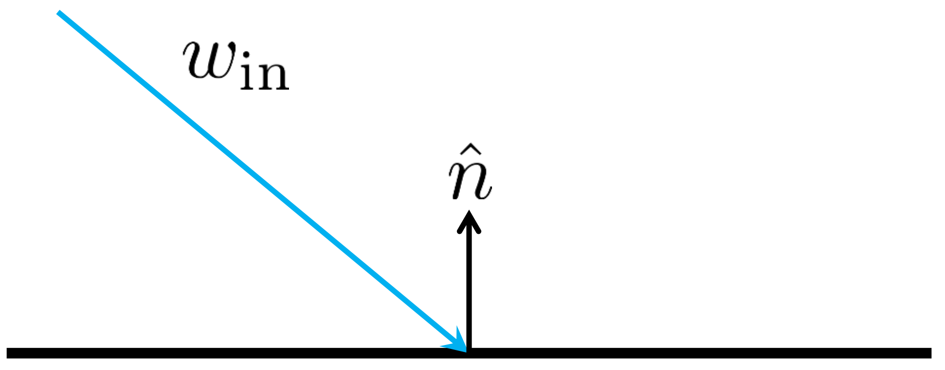
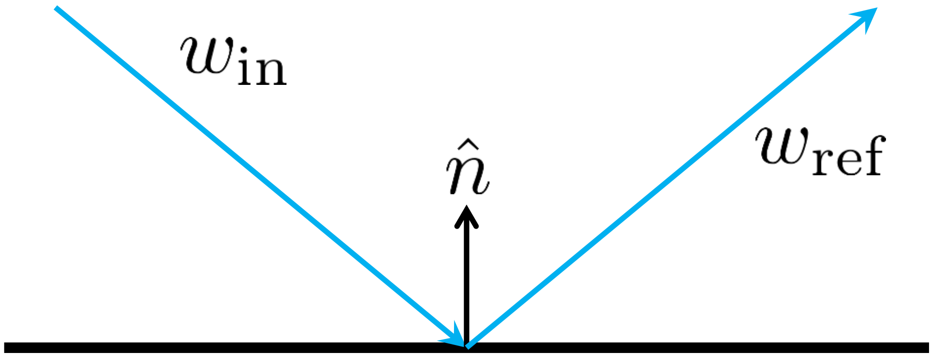
1. Incoming ray w_{in} hits surface



Reflection

Purely specular (mirrored) surface:

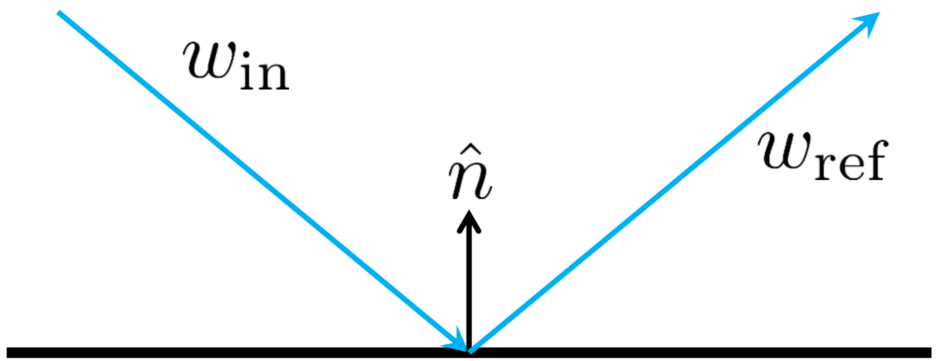
1. Incoming ray w_{in} hits surface
2. Shoot secondary **reflection ray** w_{ref}



Reflection

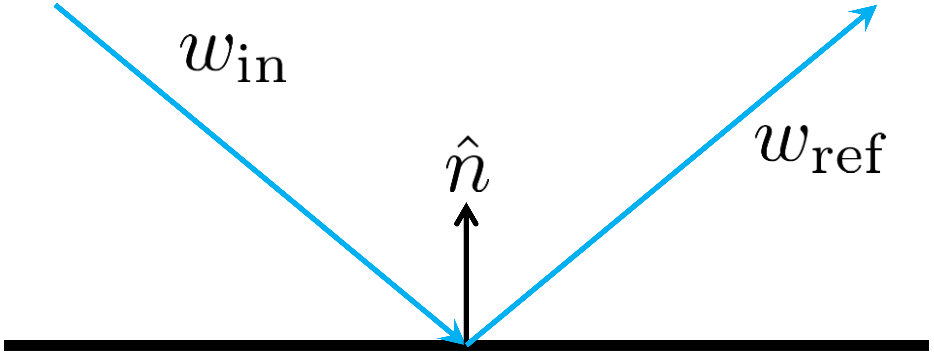
Purely specular (mirrored) surface:

1. Incoming ray w_{in} hits surface
2. Shoot secondary **reflection ray** w_{ref}
3. Set pixel color to color “seen” by w_{ref}



Choosing the Reflection Ray

Angle of reflection = angle of incidence

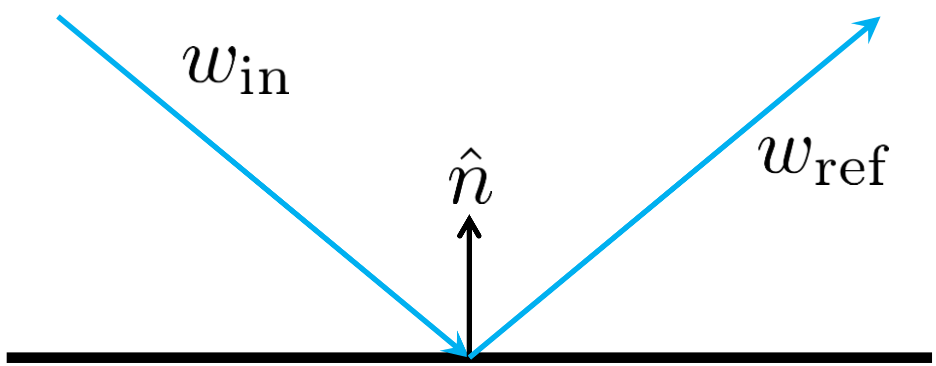


Choosing the Reflection Ray

Angle of reflection = angle of incidence

I.e. negate component of w_{in} in normal dir

- leave **tangent** component untouched



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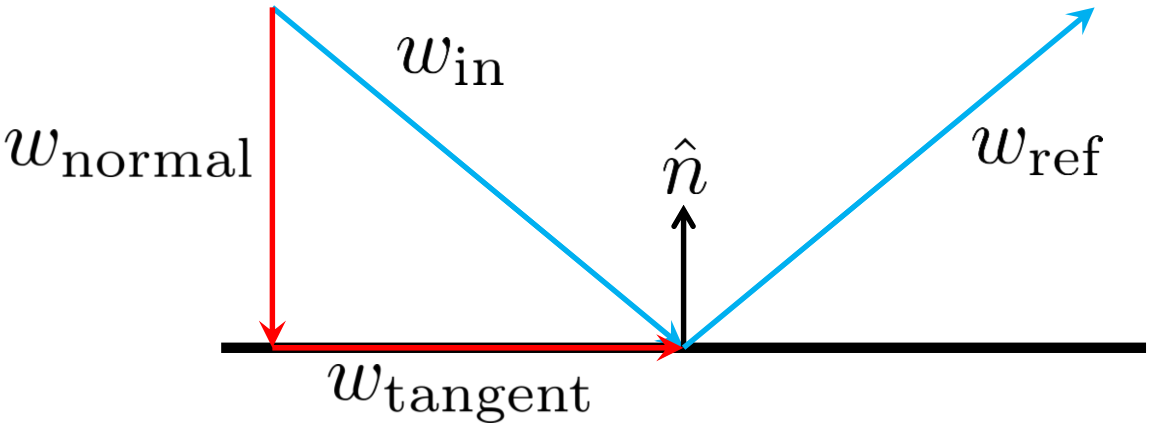

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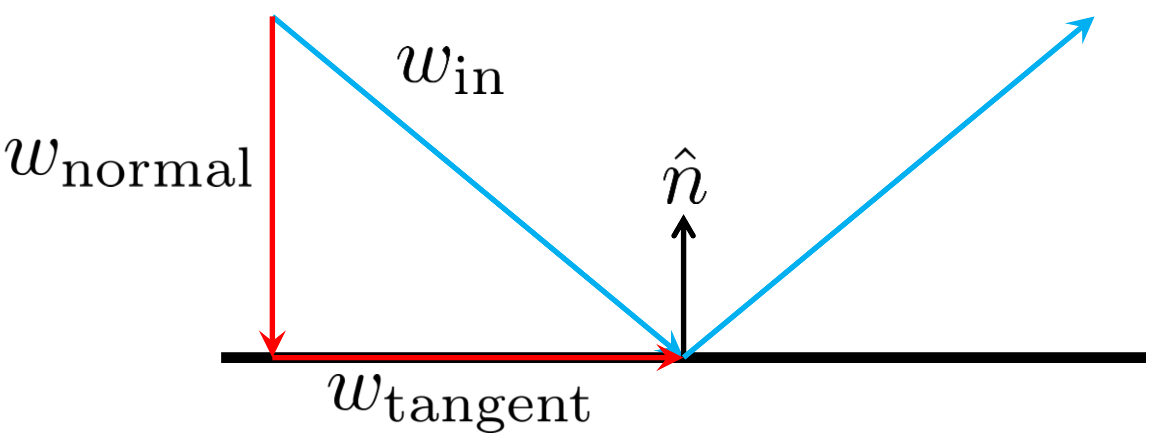
$$w_{\text{ref}} = -w_{\text{normal}} + w_{\text{tangent}}$$



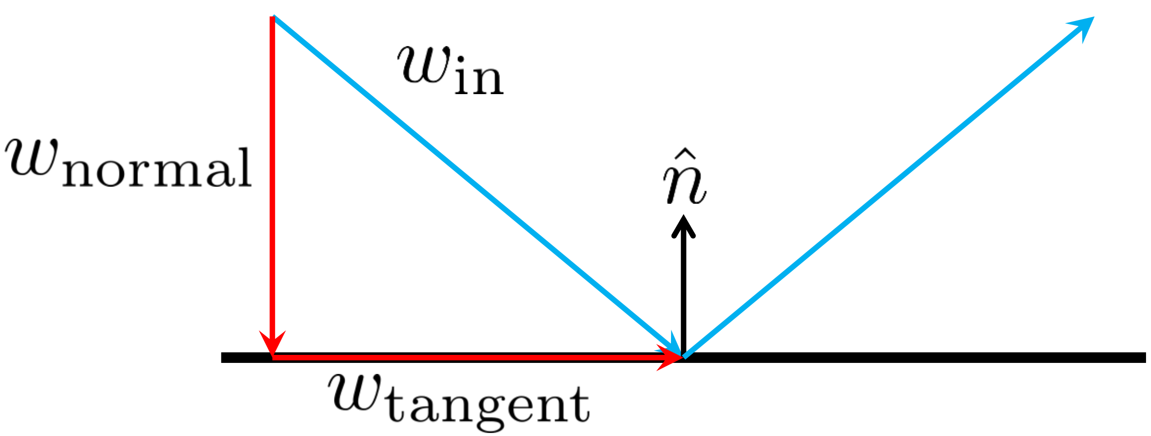
Choosing the Reflection Ray

The math:

$$w_{\text{normal}} = (w_{\text{in}} \cdot \hat{n})\hat{n}$$

$$w_{\text{ref}} = w_{\text{in}} - 2(w_{\text{in}} \cdot \hat{n})\hat{n} = (I - 2\hat{n}\hat{n}^T)w_{\text{in}}$$

$$w_{\text{ref}} = -w_{\text{normal}} + w_{\text{tangent}}$$



Reflection in Practice

Objects may not be perfectly mirrored

- blend reflected color with basic shading

Reflection in Practice

Objects may not be perfectly mirrored

- blend reflected color with basic shading

Objects have **base color**

- multiplies reflected color

Reflections in Practice

Reflection ray might hit reflective objects

- cast recursive reflection rays…
- stop after some maximum recursion limit

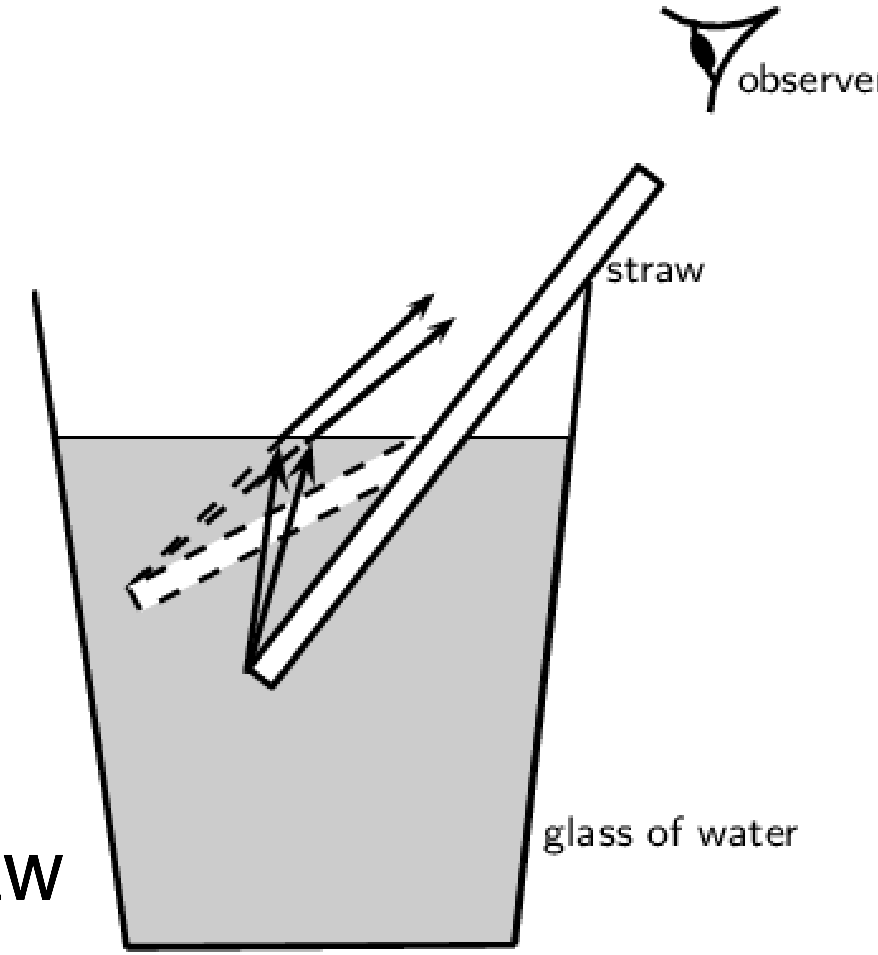
Refraction

Refraction

Light **bends** when moving between different materials

Caused by change in speed of light

We “see” dotted straw



Index of Refraction

Measures speed of light in material

$$\text{index of refraction} = \frac{\text{speed in vacuum}}{\text{speed in material}}$$

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Measures speed of light in material

$$\text{index of refraction} = \frac{\text{speed in vacuum}}{\text{speed in material}}$$

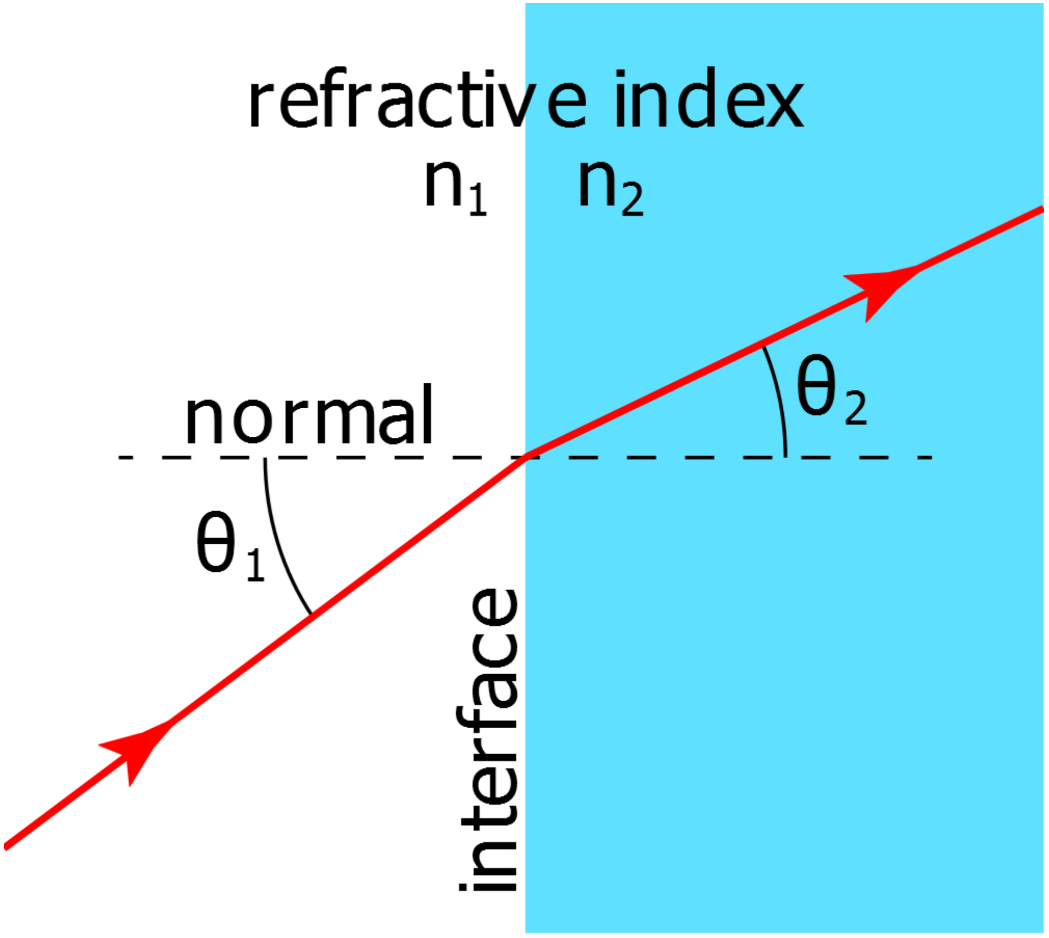
Common values:

- Vacuum: 1.0
- Air: 1.0001
- Water: 1.33
- Glass: 1.5

Snell's Law $$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

Special cases:

- $n_1 = n_2$
- $\theta_1 = 0$



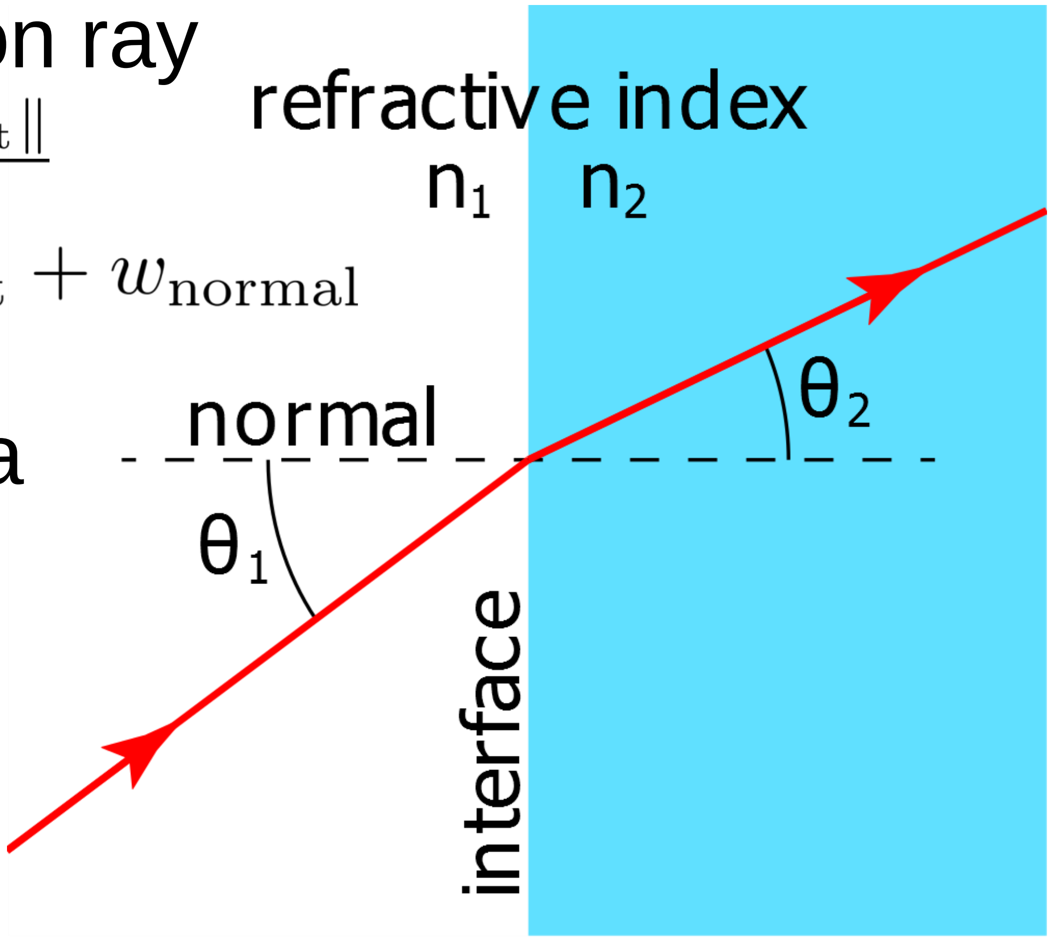
Implementing Snell's Law

Shoot refraction ray

$$\sin\theta_1 = \frac{\|w_{\text{tangent}}\|}{\|w_{\text{in}}\|}$$

$$w_{\text{rfr}} = \alpha w_{\text{tangent}} + w_{\text{normal}}$$

Solve for alpha

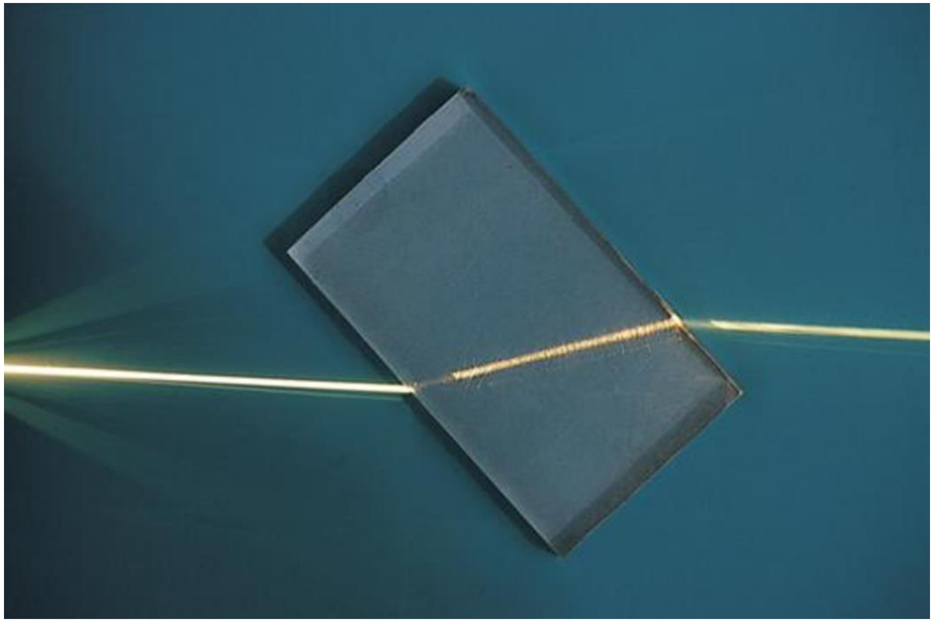


Refractions in Practice

Again, usually multiplied by a base color

Light bends when entering **and** leaving

- must detect both when ray-tracing



Reflection & Refraction Example