CSC 4356
Interactive Computer Graphics
Lecture 22: Ray Tracing (Part 2)

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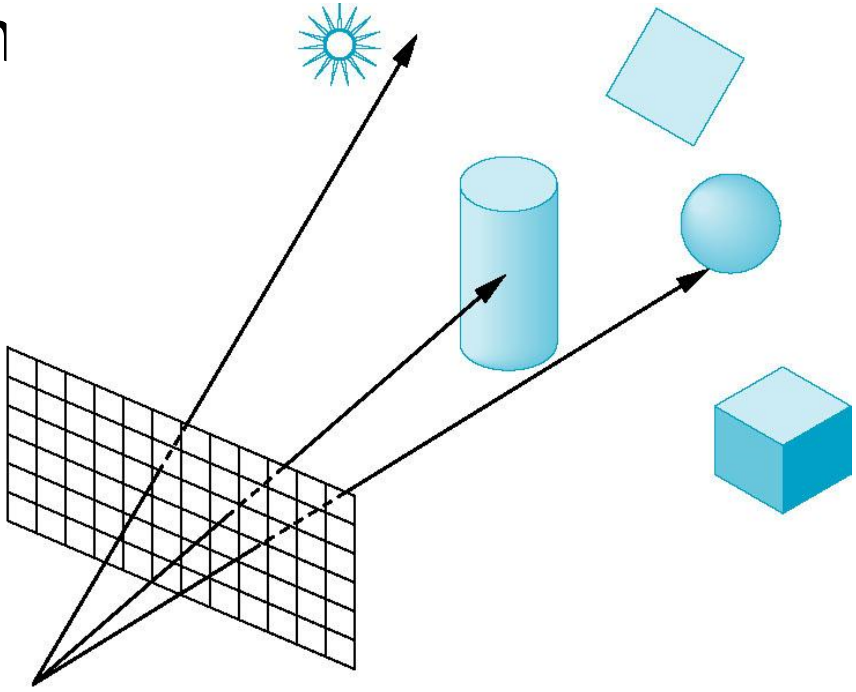
Tue & Thu: 10:30 - 11:50am
218 Tureaud Hall

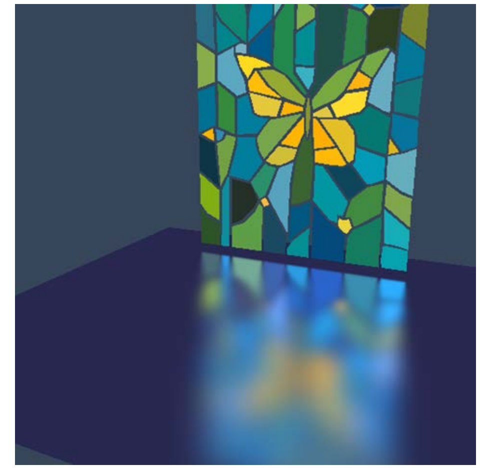
From Last Time

- Ray casting
- Ray-sphere intersection
- Ray-polygon intersection
- Ray-triangle intersection
- Shadow rays



Ray "Tracing" for More Realism

- Ray casting does not account for two important visual phenomena:
  - Mirror-like surfaces should ***reflect*** other objects in scene
  - Transparent surfaces should ***refract*** scene objects behind them

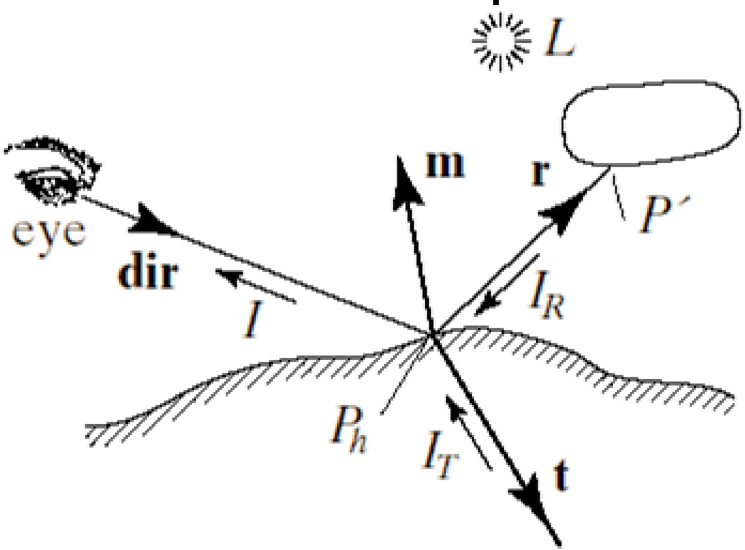


Glossy reflection

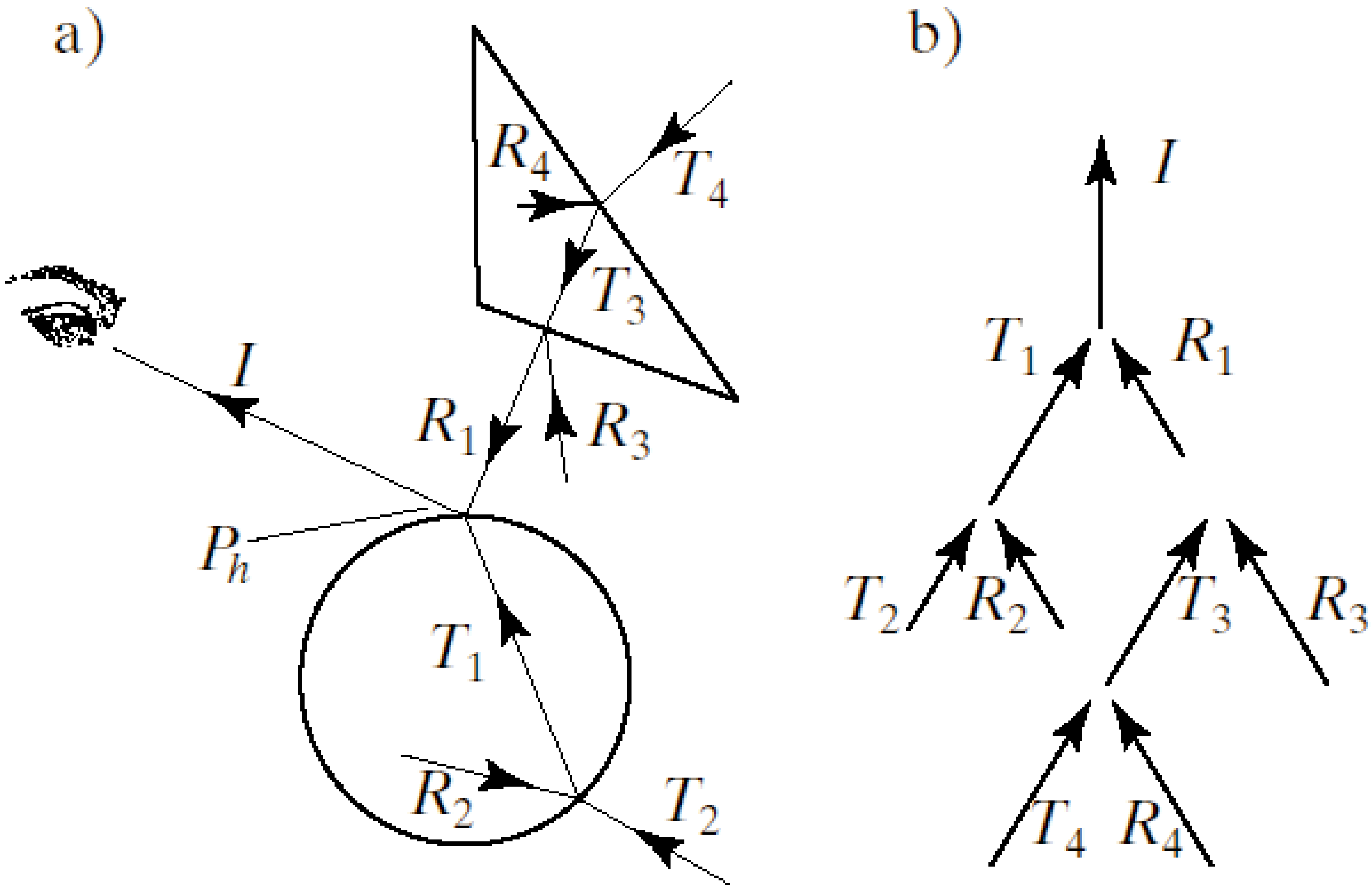
Refraction

Ray Tracing

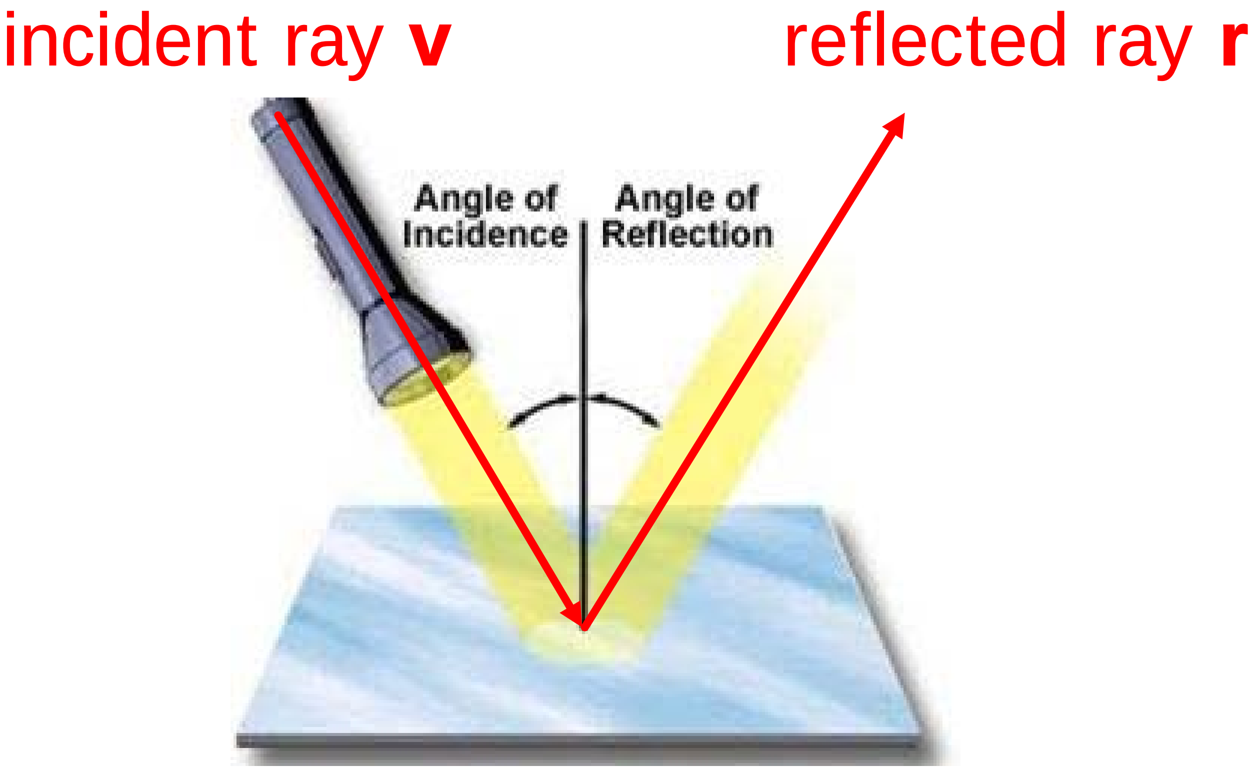
- Model: Perceived color at point **p** is an additive combination of local illumination (e.g., Phong) + reflection + refraction effects
  - Weights on last two terms are additional material properties
- Compute reflection, refraction contributions by **tracing** respective rays back from **p** to surfaces they came from and evaluating local illumination at those locations
- Apply operation **recursively** to some maximum depth to get:
  - Reflections of reflections of ...
  - Refractions of refractions of ...
  - And of course mixtures of the two



Ray Tracing: Recursion

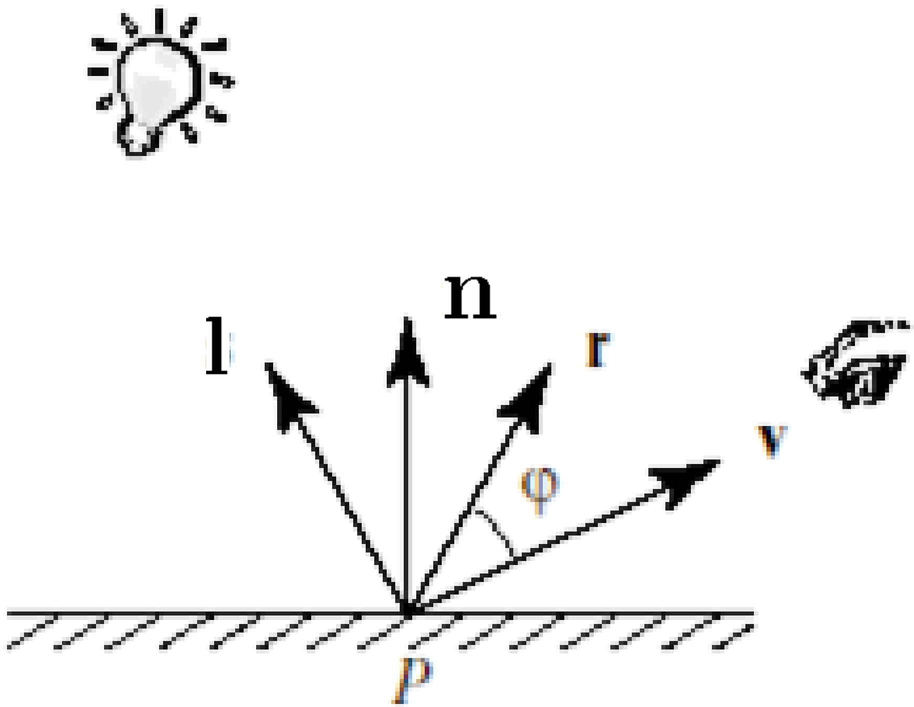


Reflections



Review: Reflection direction for Phong model

- We calculated r from normal n, light direction l via: $\mathbf{r} = 2(\mathbf{n} \cdot \mathbf{l})\mathbf{n} - \mathbf{l}$

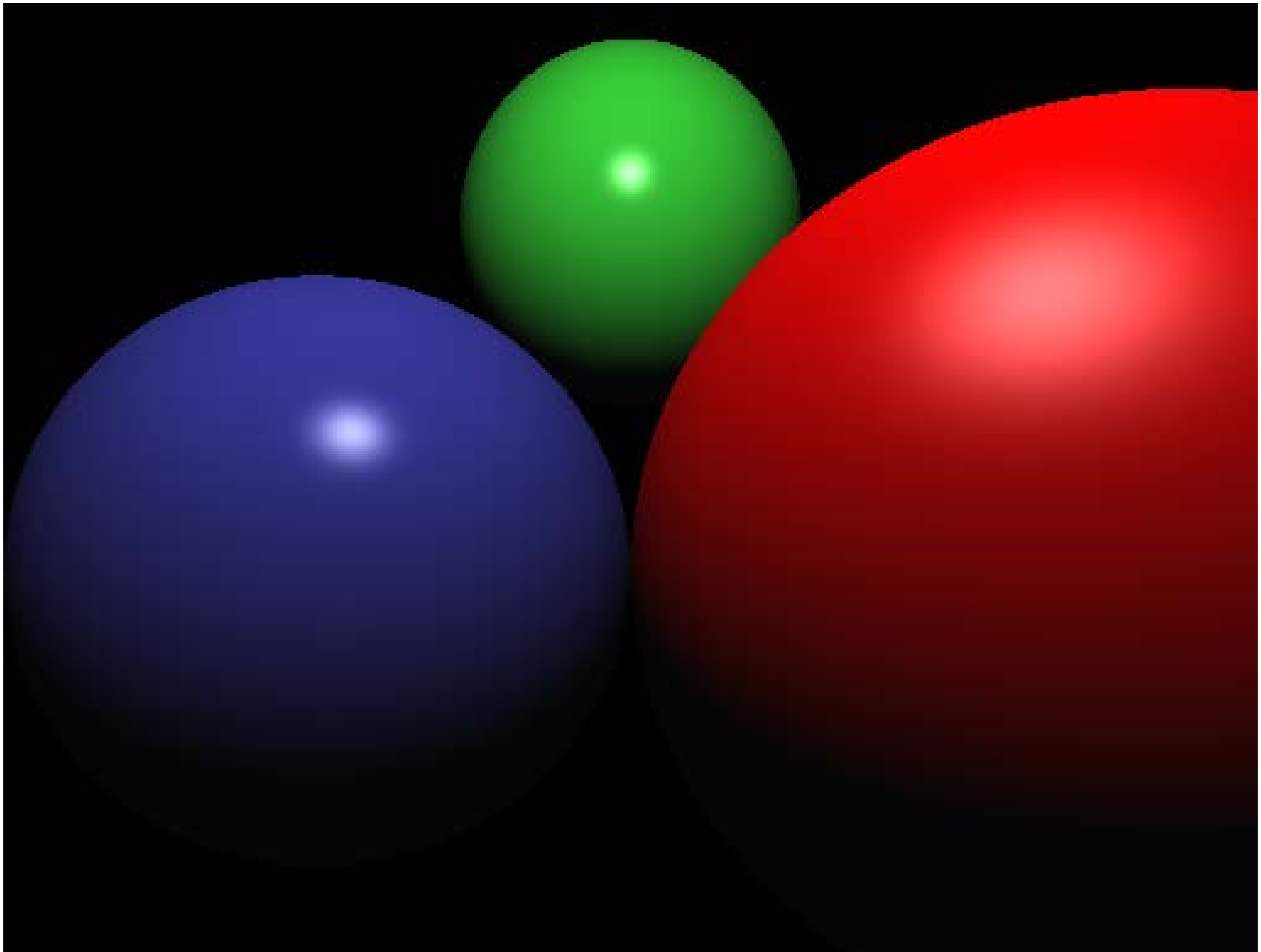


Ray Tracing Reflection Formula

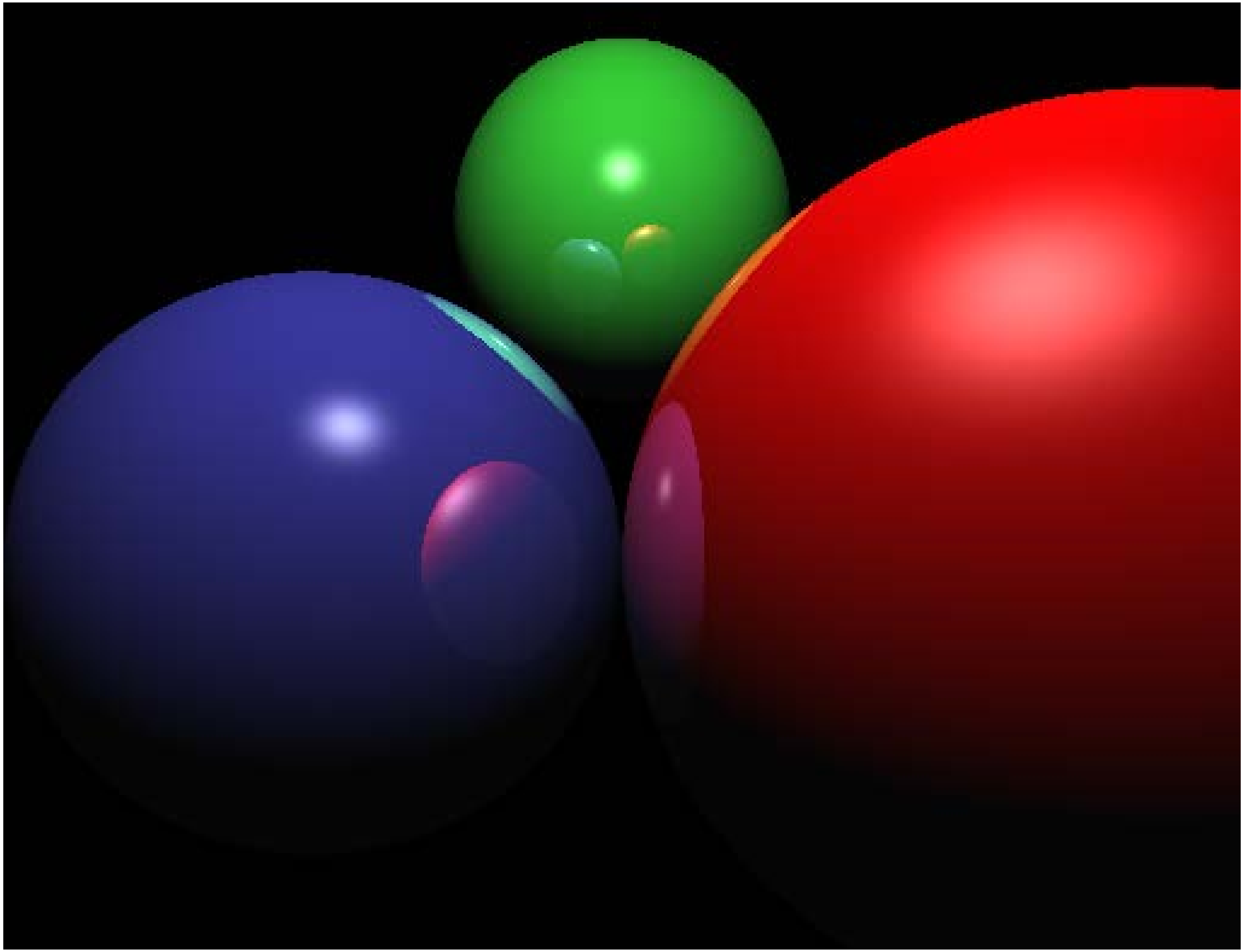
- The formula used for Phong illumination is not what we want here because our incident ray **v** is pointing **in** toward the surface, whereas the light direction **l** was pointed **away** from the surface
- So just negate the formula to get:

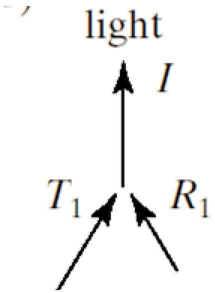
$$\mathbf{r} = \mathbf{l} - 2(\mathbf{n} \cdot \mathbf{l})\mathbf{n}$$

Example: Reflections at depth = 0

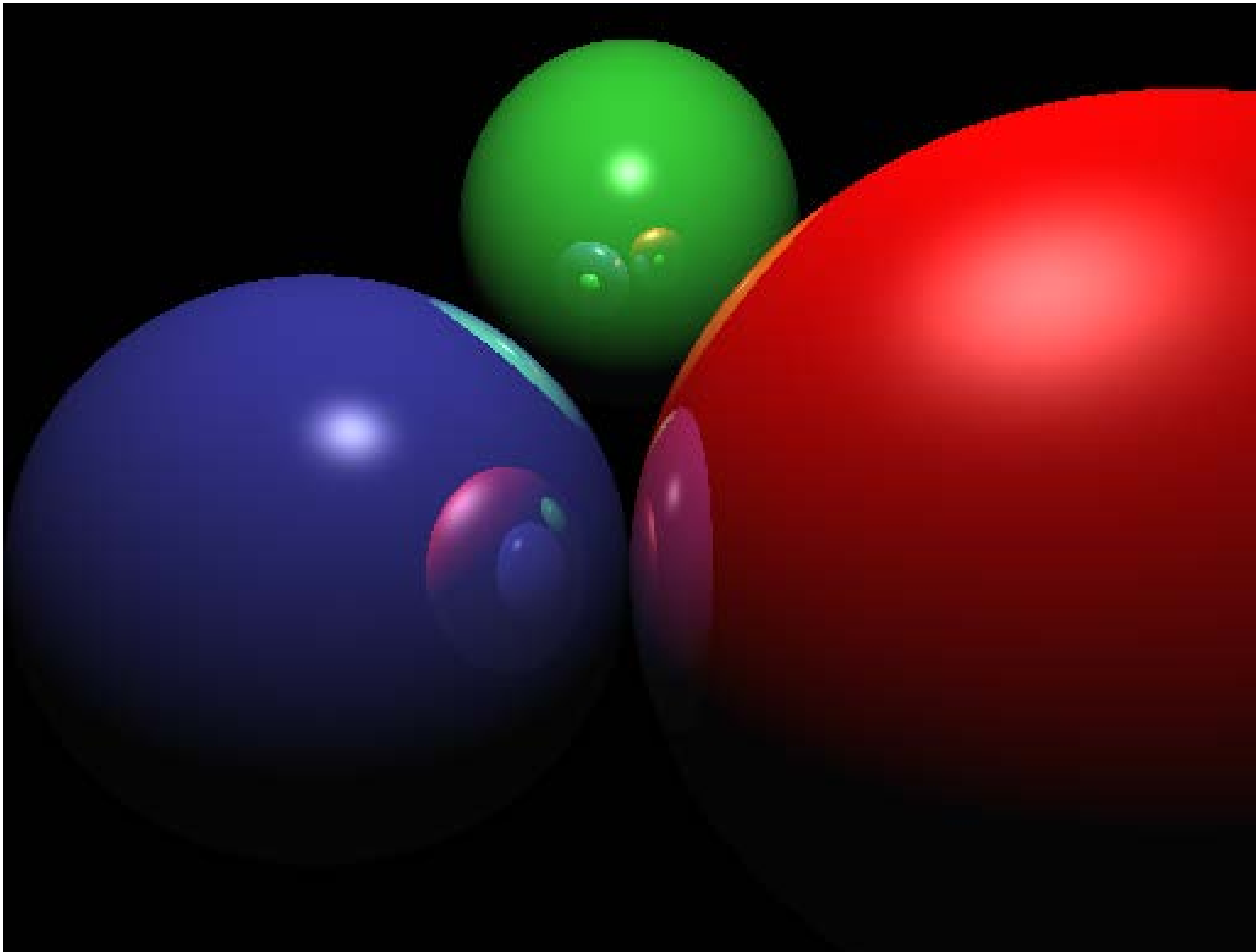


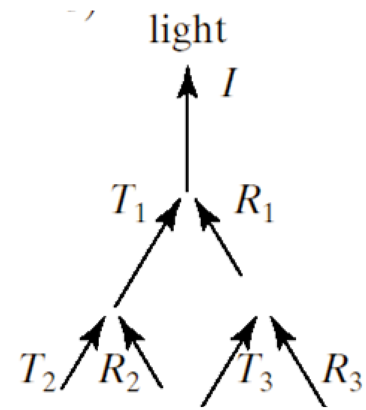
Example: Reflections at depth = 1



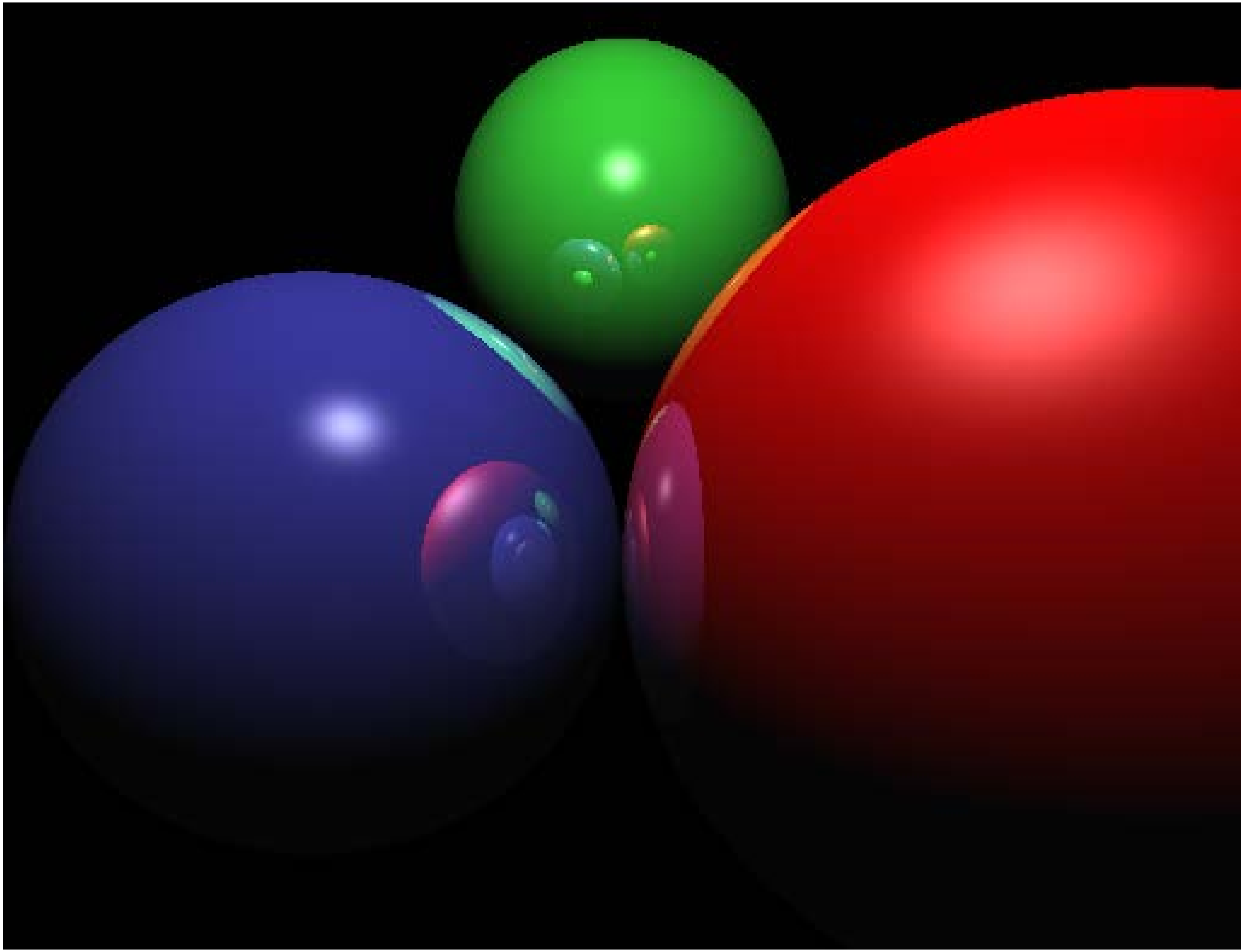


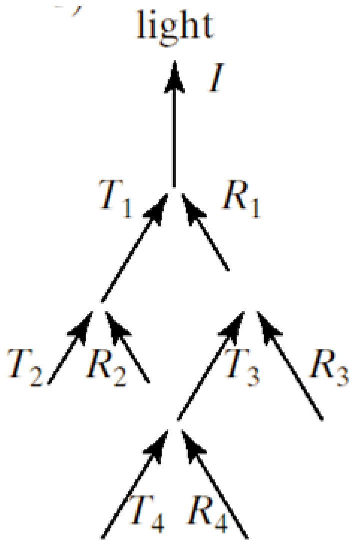
Example: Reflections at depth = 2





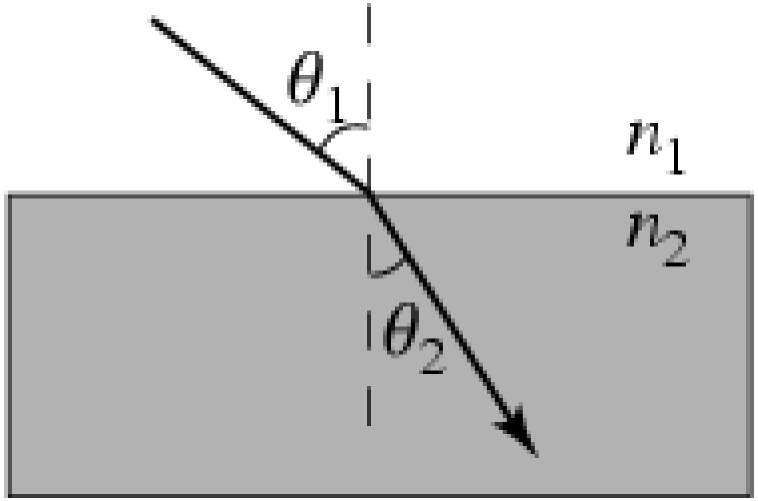
Example: Reflections at depth = 3





Refraction

- Definition: Bending of light ray as it crosses interface between media (e.g., air → glass or vice versa)
- Index of refraction (**IOR**) n for a medium: Ratio of speed of light in vacuum to speed in that medium (wavelength-dependent ⇒ prisms)
- By definition, $n \geq 1$
- Examples: n_{air} (1.0003) < n_{water} (1.33) < n_{glass} (1.52)



courtesy of Wolfram

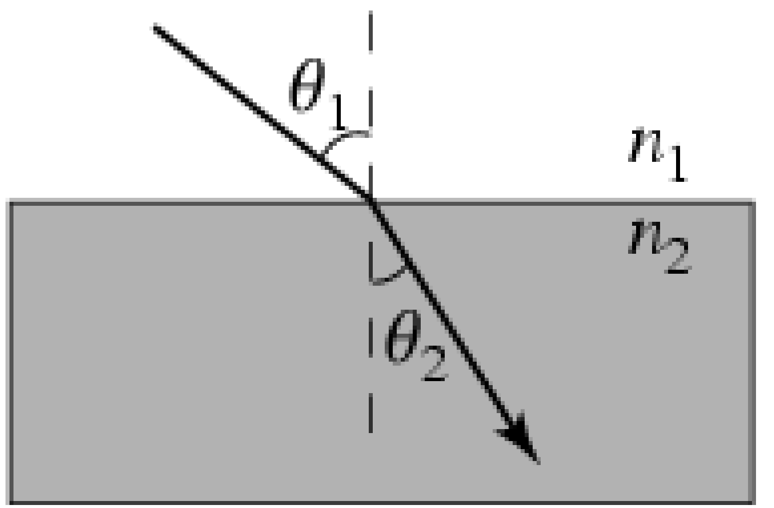
θ_1: Angle of incidence

θ_2: Angle of refraction

Snell's Law

- The relationship between the angle of incidence and the angle of refraction is given by:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



courtesy of Wolfram

Snell's Law: Implications

- Since θ ≈ sin θ over the range [0, π/2] and the angle of refraction is given by

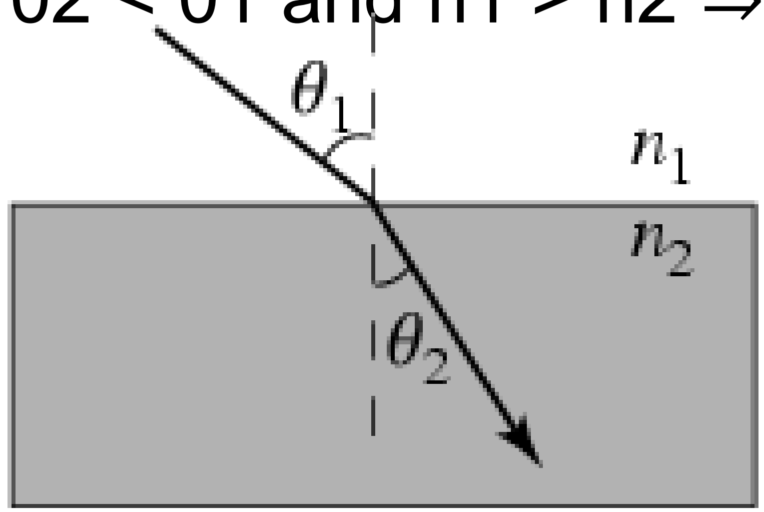
$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

- we can infer the following from their IORs:

$n1 < n2 \Rightarrow \theta2 < \theta1$ and $n1 > n2 \Rightarrow \theta2 > \theta1$

convergence

divergence



So $n_1 < n_2$
in this image
(like air to water)

Refraction Implication: the Lifeguard Problem

- Light travels shortest time!

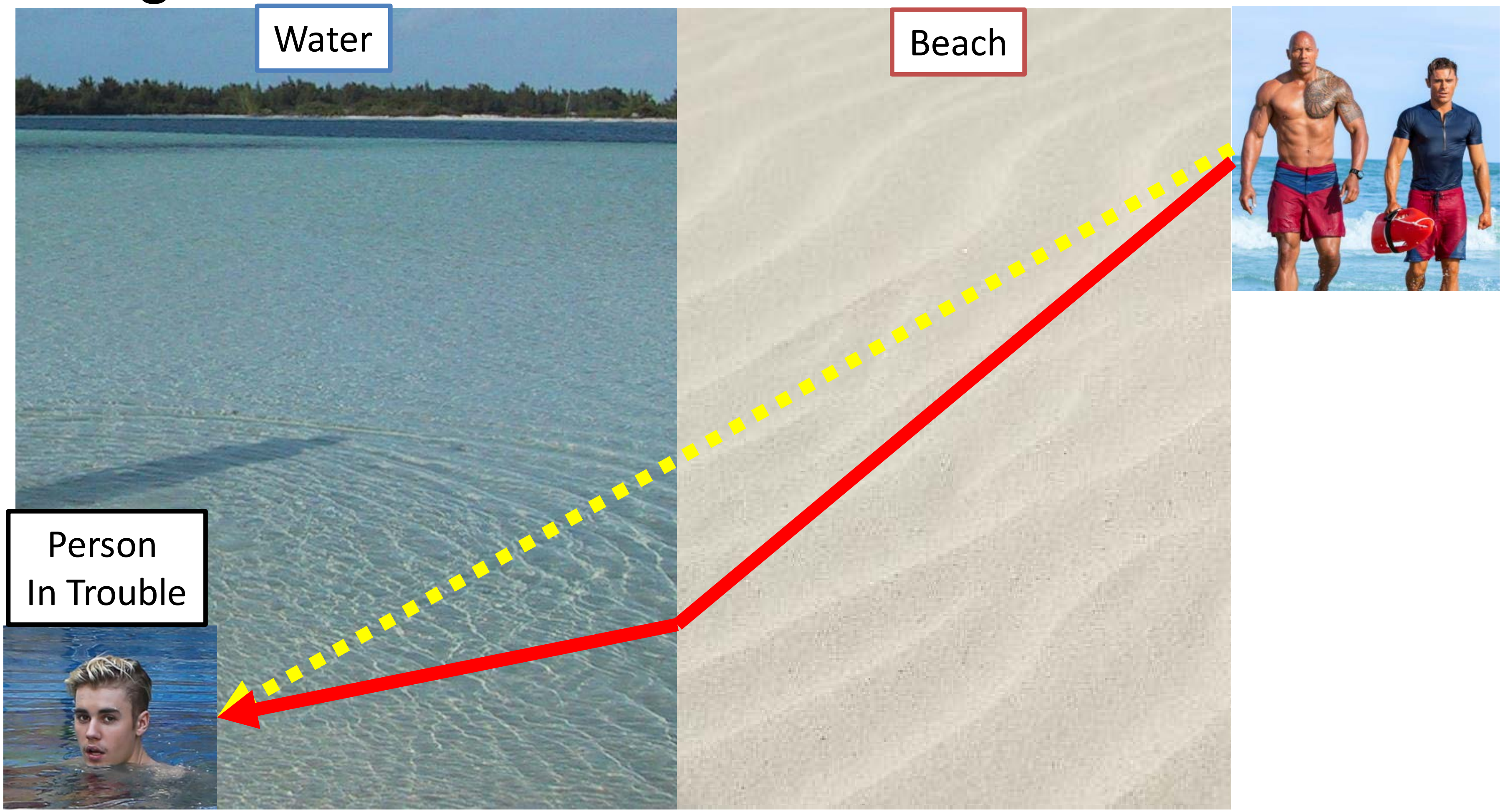
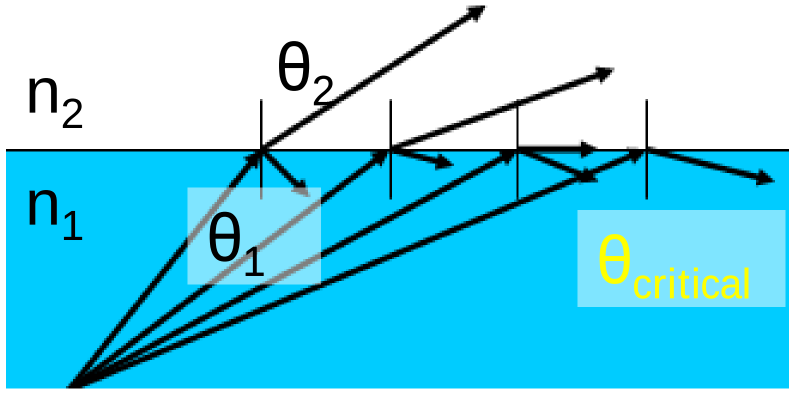


Image from Frédo Durand

Refraction: Critical Angle

- Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$ says that n1 > n2 ⇒ θ2 > θ1 (e.g., water to air), but biggest angle θ2 that exiting ray can be bent is π/2 (along tangent to the surface)
- Thus, no light escapes—all light is reflected internally—for θ1 greater than or equal to the **critical angle** of:

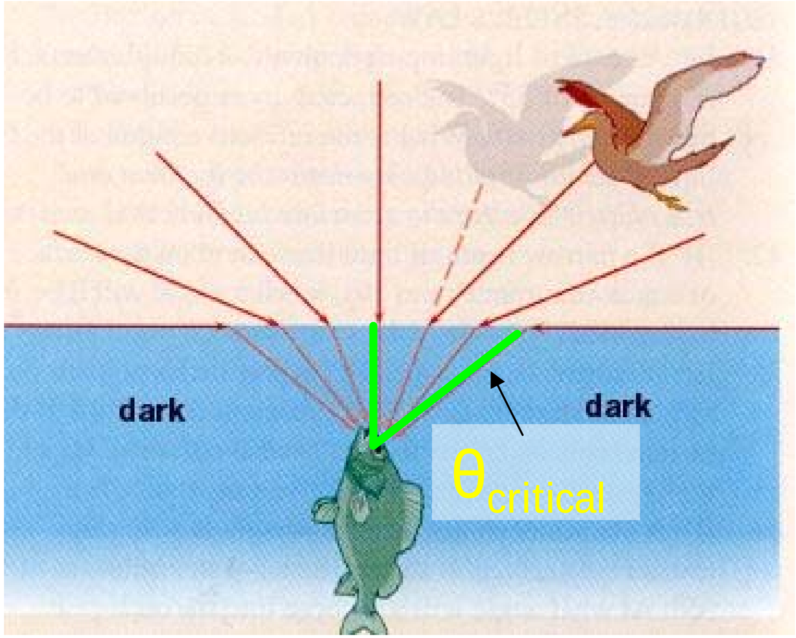
$$\theta_{critical} = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$



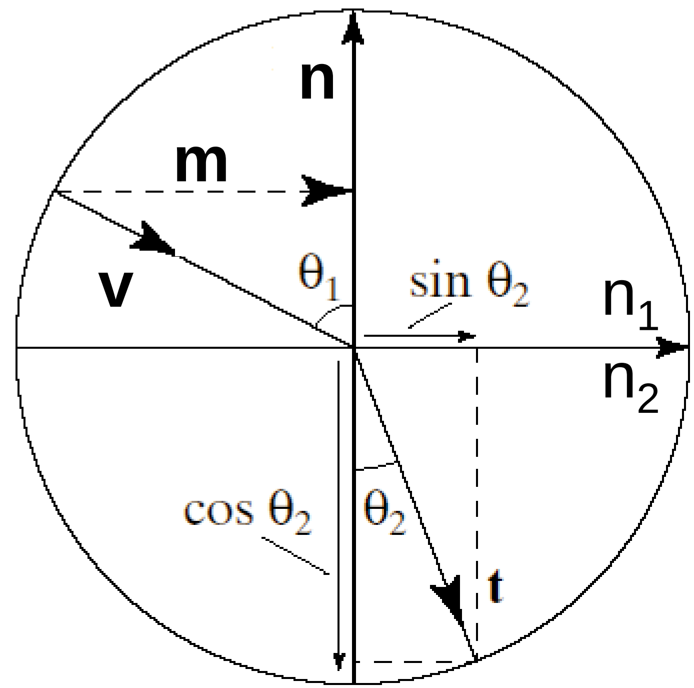
Critical Angle: Example

- Going from water (IOR = 1.33) to air (IOR = 1.00), we have:

$$\theta_{critical} = \sin^{-1}\left(\frac{1.00}{1.33}\right) \approx 48.75^\circ$$



Computing the Transmission Direction **t**



$$n = \frac{n_1}{n_2}$$

$$c_1 = \cos\theta_1 = -\mathbf{v}\cdot\mathbf{n}$$

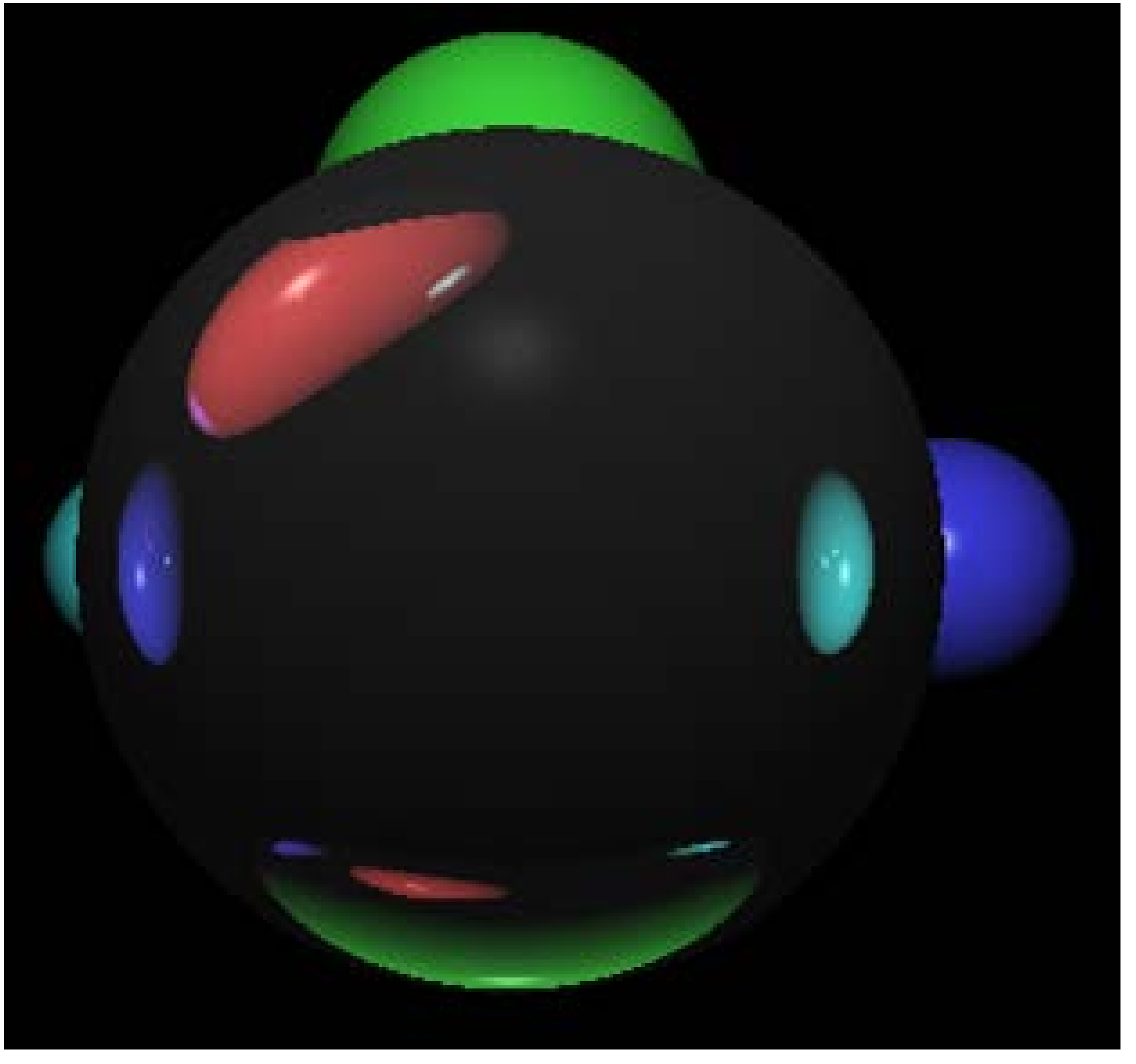
$$c_2 = \cos\theta_2 = \sqrt{1 - n^2(1 - c_1^2)}$$

$$\mathbf{t} = n\mathbf{v} + (nc_1 - c_2)\mathbf{n}$$

Total internal reflection happens when the term in the square root above isn't positive, which is when

$$n^2(1 - c_1^2) \geq 1$$

Example: Refraction



Example: Refraction

Next Time …

- Advanced ray tracing
  - Acceleration, anti-aliasing, lens blur, etc.
  - Textbook Chapter 21-1 (page 646-654)
- Programming assignment 4 will be posted TODAY
  - Implement basic ray tracing (ray-primitive intersection, recursive ray tracing, etc.)
  - Due on 12/5