VGP352 – Week 3

- Agenda:
  - ~~Quiz #1~~
  - Mipmapping normal maps
  - Improving the reflection model, part 1

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Specular

- Does asphalt exhibit specular reflection?

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Specular

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Specular

- Does asphalt exhibit specular reflection?

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Specular

- Does asphalt exhibit specular reflection?

No specular highlight

Large specular highlight

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Changing Specular

- What's happening?

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Changing Specular

- What's happening?
  - Specular reflection depends on the relative orientation of the view and reflection vectors
    - That's $\mathbf{v} \cdot \mathbf{r}$ from the Phong lighting model
  - It also depends on the relative orientation of the reflection vector and the surface
    - Our current lighting model doesn't account for this!

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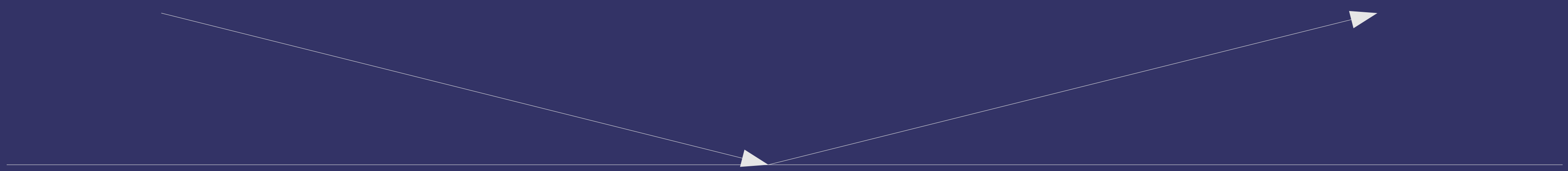
Changing Specular



Large specular highlight

Smaller specular highlight

No specular highlight

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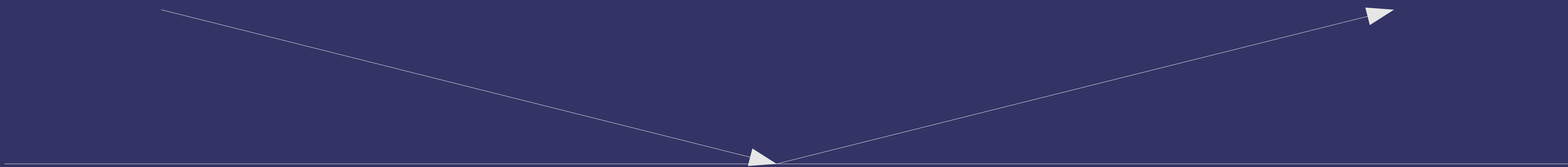
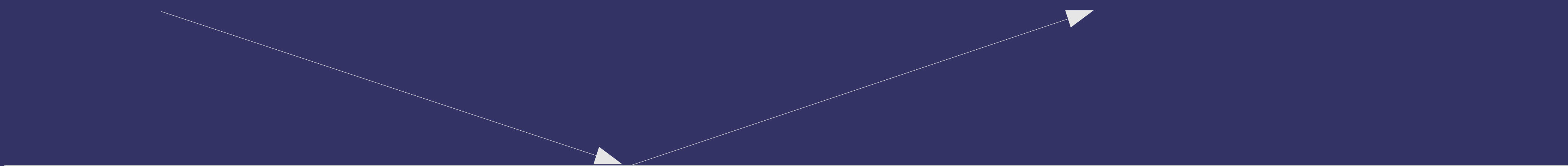
Reflection vs. Refraction



~~Large specular highlight~~

Lots of reflection



~~Smaller specular highlight~~

Some reflection

~~No specular highlight~~

No reflection

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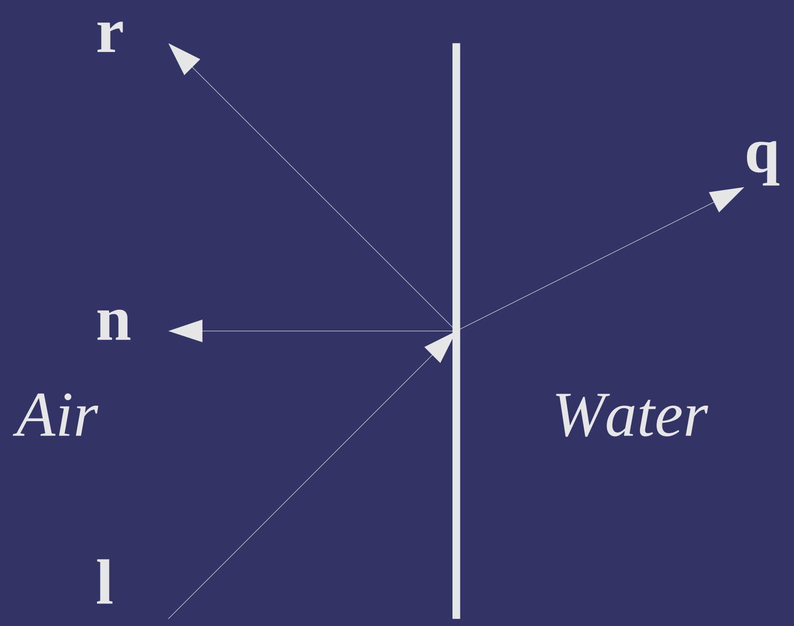
Wave Theory – Refraction

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



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Reflection vs. Refraction

- Ratio of reflection to refraction depends on the angle between the light and the normal at the interface
  - The larger the angle between the normal and the light, the more light is reflected
  - The effect is like a rock skipping on water
    - The greater the angle between the rock's velocity and the water's surface tangent, the more skipping

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Fresnel Reflection

- Named after French physicist Augustin-Jean Fresnel
  - It's French... It's pronounced *fray-NELL*
- Light moves at different speeds through different materials
  - The ratio of the speed of light in a vacuum to the speed in a particular material is the *refractive index* of that material
  - Glass has an index of refraction of ~1.5

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Fresnel Reflection

- When light passes between material with differing indicies of refraction:
  - The light changes velocity
    - Both speed *and* direction change
    - Wave theory of light: the change in speed causes the change in direction
  - Some of the light is reflected
  - The remaining light is refracted
    - This light passes into the material

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Reflection Math

- The fraction of light reflected, $\mathrm{R}(\theta)$, is:

$$\mathrm{R}(\theta)=\frac{1}{2}\left(\frac{(g-c)}{(g+c)}\right)^2\left(1+\left(\frac{c(g+c)-(n_i/n_t)^2}{c(g-c)+(n_i/n_t)^2}\right)^2\right)$$

Where:

$$c = (n_i/n_t)(\cos\theta)$$

$$g = \sqrt{1+c^2-(n_i/n_t)^2}$$

  - n_i = refractive index of the first material
  - n_t = refractive index of the second material
  - θ = angle between the normal and the light vector
  - Sometimes $\mathrm{R}(\theta)$ is written as F

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Reflection Math

- Yewouch! That math is complex and expensive
- A good approximation exists:

$$R(\theta) = R_0 + (1 - R_0)(1 - \cos\theta)^5$$

  - R_0 is the reflectance at normal incidence
    - True value of the Fresnel term when $\theta = 0°$
    - Calculated in the application and passed in as a uniform
  - Known as “Schlick's approximation”

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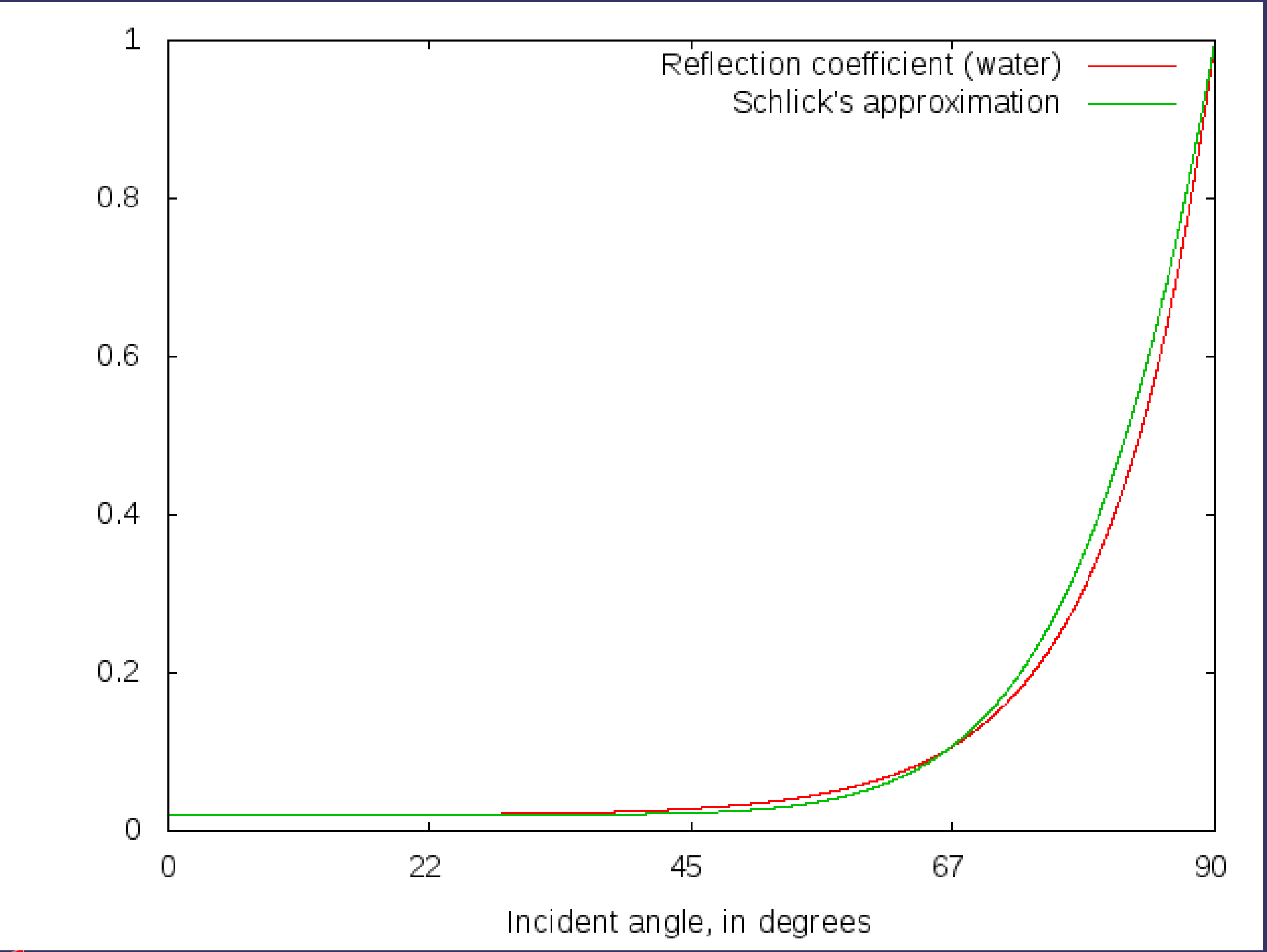
Reflection Math



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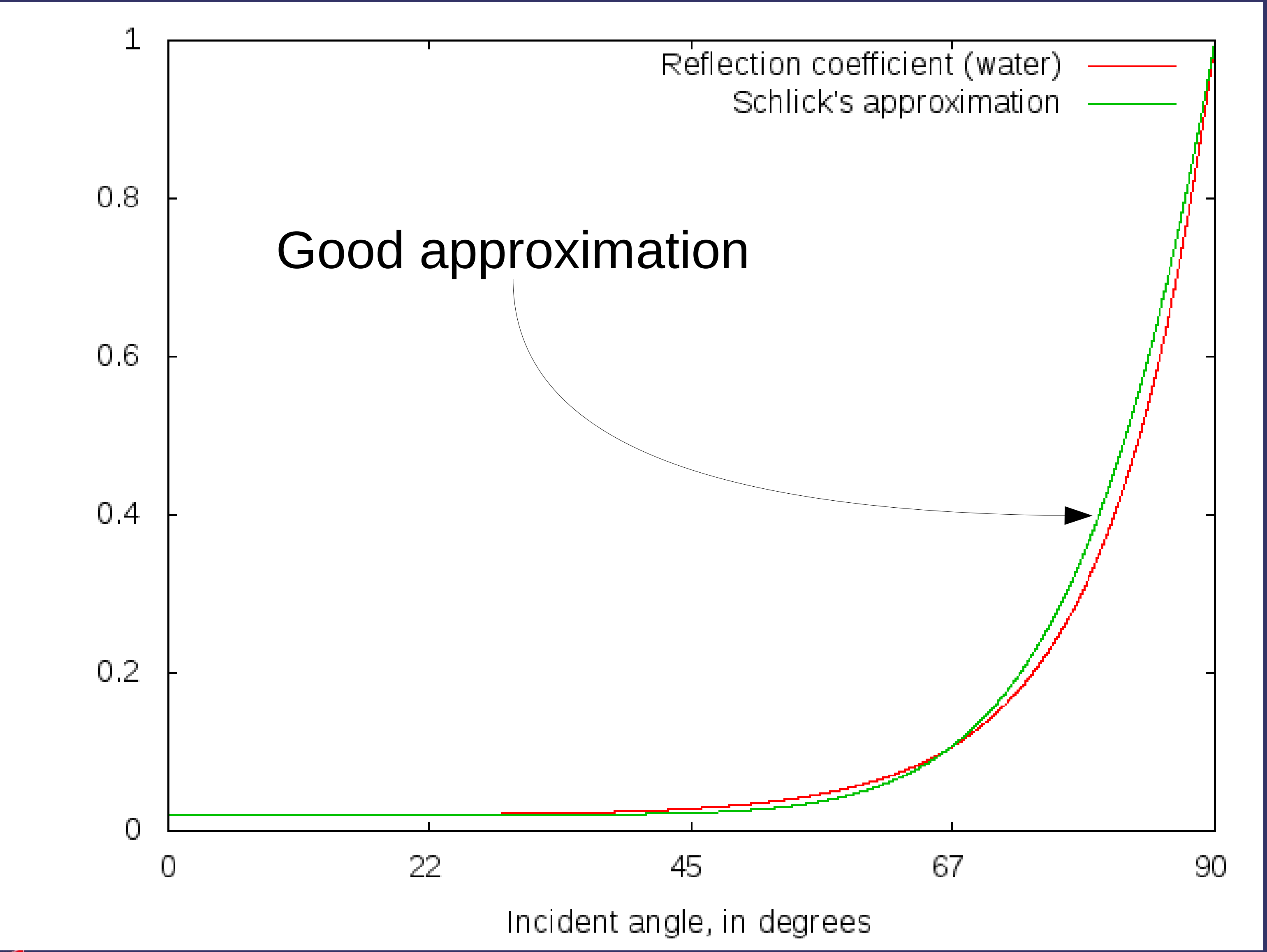
Reflection Math



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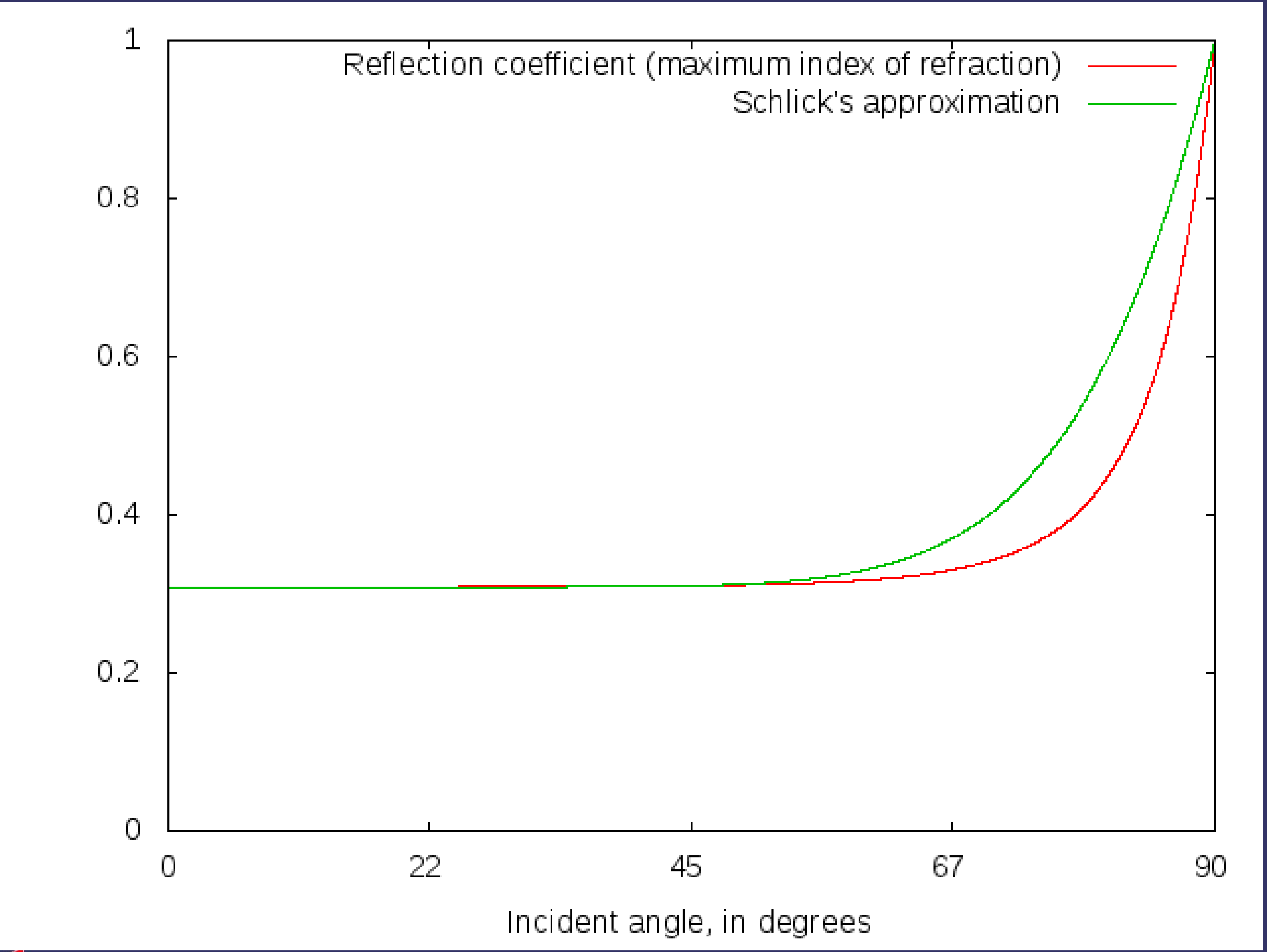
Reflection Math



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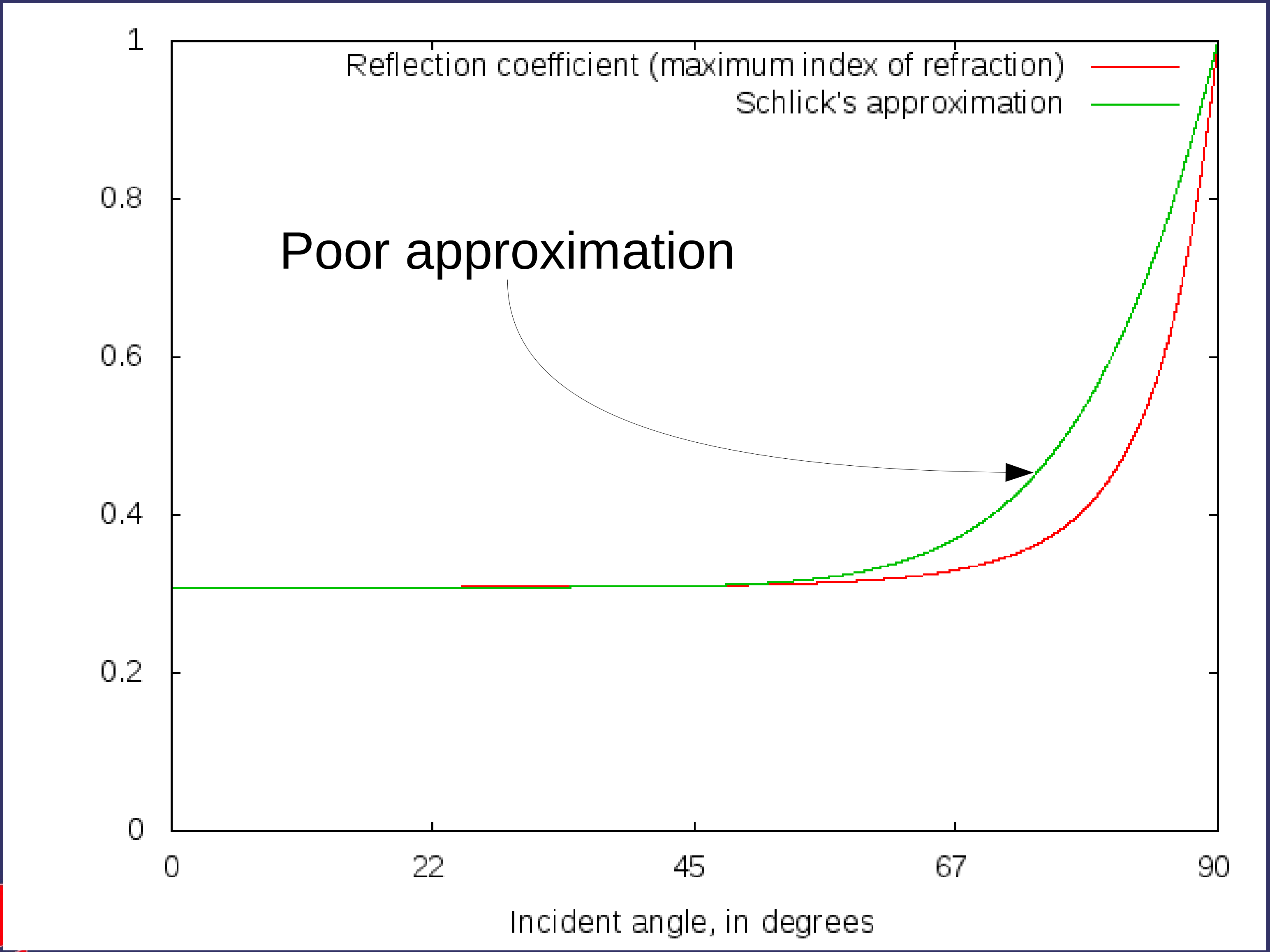
Reflection Math



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Reflection Math

$$\text{Let } \theta = 0^\circ:$$

$$\begin{aligned}
c &= (n_i/n_t)\cos 0^\circ = (n_i/n_t) \\
g &= \sqrt{1 + c^2 - c^2} = 1 \\
\mathrm{R}(0^\circ) &= \frac{1}{2}\left(\frac{(1-c)}{(1+c)}\right)^2 \left(1 + \left(\frac{c(1+c) - c^2}{c(1-c) + c^2}\right)^2\right) \\
&= \frac{1}{2}\left(\frac{(1-c)}{(1+c)}\right)^2 \left(1 + \left(\frac{c + c^2 - c^2}{c - c^2 + c^2}\right)^2\right) \\
&= \frac{1}{2}\left(\frac{(1-c)}{(1+c)}\right)^2 (2) \\
&= \left(\frac{(1-c)}{(1+c)}\right)^2
\end{aligned}$$

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Reflection Math

Since $c = \left(n_i / n_t\right)$:

$$\left(\frac{(1-c)}{(1+c)}\right)^2 = \left(\frac{\left(1-\frac{n_i}{n_t}\right)}{\left(1+\frac{n_i}{n_t}\right)}\right)^2$$

$$= \left(\frac{\left(\frac{n_t-n_i}{n_t}\right)}{\left(\frac{n_t+n_i}{n_t}\right)}\right)^2$$

$$= \left(\left(\frac{n_t-n_i}{n_t}\right)\left(\frac{n_t}{n_t+n_i}\right)\right)^2$$

$$\mathrm{R}\left(0^\circ\right) = \left(\frac{n_t-n_i}{n_t+n_i}\right)^2$$

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Fresnel Reflection in Lighting

- Simulate a diffuse surface with a shinny coating:

$$\mathbf{k} = (1 - F)\mathbf{k}_d + F\,\mathbf{k}_s$$

  - The Fresnel term determines what part of the light is reflected by the specular coating
  - The light that isn't reflected by the specular coating is reflected by the diffuse layer
  - GLSL `mix` function does the interpolation:

```
gl_FragColor = mix(kd, ks, F);
```


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Fresnel Reflection and Materials

- Dielectric materials exhibit a strong Fresnel factor
  - Dielectric means that it does *not* conduct electricity
  - Plastic, glass, automotive paint, etc. are dielectic and have strong Fresnel factors
  - Metal is a conductor and has almost no Fresnel factor
    - This fact will be very important later...

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References

Wloka, Matthias, Fresnel Reflection. NVIDIA. July 2002. http://developer.nvidia.com/object/fresnel_wp.html

Westin, Stephen. “Fresnel Reflectance.” September 2007. http://www.graphics.cornell.edu/~westin/misc/fresnel.html

“Reflection and Refraction of Light (Fresnel Formulas).” http://physics-animations.com/Physics/English/rays_txt.htm

http://en.wikipedia.org/wiki/Fresnel_equations

http://en.wikipedia.org/wiki/Schlick%27s_approximation

Google for “refractive index <some material>”

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Reading for Next Week

Prepare for next week:

Cook, Robert L. and Torrance, Kenneth E., "A Reflectance Model for Computer Graphics." In *SIGGRAPH ’81: Proceedings of the 8th Annual Conference on Computer Graphics and Interactive Techniques*, pages 307–316. ACM, 1981. http://graphics.pixar.com/library/ReflectanceModel/

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Next week...

- Quiz #1
  - Material from week 1 and week 2 only!
  - Three questions:
    - Bézier curves
    - Surface space
    - Normal maps
- BRDFs, part 1
  - Common ideas and terminology
  - Cook-Torrance BRDF

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