VGP352 – Week 3

⇨ Agenda:

- Quiz #1
- Render to texture
- Reflection mapping
  - Review
  - Rendering to a reflection map
- Improving the reflection model
  - Reflection maps as better lights
  - Fresnel reflections

Render to Texture

▷ Several methods exist

- Render to framebuffer, the copy the result to a texture
  - Use `glCopyTexImage2D`
- Render to a pixel buffer (pbuffer), then bind to a texture
  - Platform dependent (i.e., is different on Linux, Windows, and Mac OS)
- Use framebuffer objects to render direct to a texture

Why render to a texture?

▷ Many effects can be created by rendering to one or more textures, then using those textures to render the final scene

- – Shadow maps

- – Dynamic environment maps

- – Pre-baking procedural textures

Copy to Texture

⇨ Very easy:

- Draw to backbuffer

- Copy resulting image to a texture using either `glCopyTexImage2D` or `glCopyTexSubImage2D`

- *That's it*

Copy to Texture

⇨ Problems:

- Must perform extra copies – slow

- Must perform extra buffer clears

- Window must be at least as large as the largest desired texture

- Results can be corrupted if the window is partially obscured

- Can't generate a texture when a frame is partially rendered

  - The back-buffer already has part of the final scene in it!

Framebuffer Objects

⇨ Warning: FBOs have a fairly steep learning curve

- The ARB spent over two years developing the interface

- It builds on the familiar texture interfaces, but is still very different

Framebuffer Objects

⇨ Create and bind an FBO

```
void glGenFramebuffersEXT(GLsizei n,
     GLuint *framebuffers);

void glBindFramebufferEXT(GLenum target,
     GLuint framebuffer);
```

Framebuffer Objects

▷ Attach one or more renderable objects to it

- 1D, 2D, and 3D versions exist

```
void glFramebufferTexture2DEXT (GLenum target,
    GLenum attachment, GLenum textarget,
    GLuint texture, GLint level);

void glFramebufferRenderbufferEXT(
    GLenum target, GLenum attachment,
    GLenum renderbuffertarget,
    GLuint renderbuffer);
```

Framebuffer Objects

▷ Attach one or more renderable objects to it

 – 1D, 2D, and 3D versions exist

```
void glFramebufferTexture2DEXT (GLenum target,
    GLenum attachment, GLenum textarget,
    GLuint texture, GLint level);
```

```
void glFramebufferRenderbufferEXT(
    GLenum target, GLenum attachment,
    GLenum renderbuffertarget,
    GLuint renderbuffer);
```

Selects how the buffer is used:

 – Color buffer: `GL_COLOR_ATTACHMENT0`

 – Depth buffer: `GL_DEPTH_ATTACHMENT`

 – Stencil buffer: `GL_STENCIL_ATTACHMENT`

Framebuffer Objects

▷ After making all of the desired attachments:

- Disable outputs that don't have attachments

  - Use `glColorMask` or `glDisable` with `GL_DEPTH_TEST` or `GL_STENCIL_TEST`

- Make sure the FBO is acceptable by calling

  ```
  GLenum glCheckFramebufferStatusEXT(
      GLenum target);
  ```

  - Some hardware can't handle some combinations of attachments

  - Some combinations are just wrong

- Reset the viewport

- Draw!

Framebuffer Objects

▷ Use textures that were rendered to just like usual

- You cannot render to a texture layer that might be used for rendering (i.e., no feedback loop)

- You cannot use `GL_GENERATE_MIPMAPS` with FBO rendered textures

```
void glGenerateMipmapEXT(GLenum target);
```

Renderbuffers vs. Textures

⇨ Two types of buffers can be attached to an FBO:
- Texture – texturable and renderable
- Renderbuffer – renderable only

⇨ Why do renderbuffers exist?

Renderbuffers vs. Textures

⇨ Two types of buffers can be attached to an FBO:
- Texture – texturable and renderable
- Renderbuffer – renderable only

⇨ Why do renderbuffers exist?
- It's the only way to do stencil
    - When FBOs were created, there were no integer textures
    - GL 3.0 adds integer textures, so renderbuffers may eventually be depreceated
- Driver may be able to use a better format if the object won't be texturable
    - Some hardware needs the whole mipmap stack allocated up-front

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Renderbuffers

▷ Similar interface to textures:

```
void glGenRenderbuffersEXT(GLsizei n,
     GLuint *renderbuffers);

void glRenderbufferStorageEXT(GLenum target,
     GLenum internalformat,
     GLsizei width, GLsizei height);

void glDeleteRenderbuffersEXT(GLsizei n,
     const GLuint *renderbuffers);
```

Dimensions and Dimensionality

▷ Dimensions (i.e., height and width) of all attachments must match

   – This requirement is relaxed in OpenGL 3.0 and `GL_ARB_framebuffer_object`

▷ Dimensionality (i.e., 1D or 2D) of all attachments must match

   – A 2D "slice" of a 3D texture is attached, so it is treated as a 2D texture for this purpose

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References

Jones, Rob, "OpenGL Framebuffer Object 101."
http://www.gamedev.net/reference/programming/features/fbo1/

Green, Simon, The OpenGL Framebuffer Object Extension. NVIDIA. 2004.
http://developer.nvidia.com/object/gdc_2005_presentations.html

`GL_EXT_framebuffer_object` and related extension specifications:

- http://www.opengl.org/registry/specs/EXT/framebuffer_object.txt
- http://www.opengl.org/registry/specs/EXT/framebuffer_blit.txt
- http://www.opengl.org/registry/specs/EXT/framebuffer_multisample.txt
- http://www.opengl.org/registry/specs/ARB/framebuffer_object.txt

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Reflection Mapping

▷ Forms of reflection mapping are classified by the shape used to simulate the environment

- Cylindrical

- Hemispherical

- Spherical

- Cube

- Dual-paraboloid

Reflection Mapping – Cube

▷ Extend **r** to intersect unit cube surrounding point

Reflection Mapping – Cube

⇨ Pros:

- Trivial to implement

- Easy to render to reflection map

⇨ Cons:

- Requires hardware support

- More difficult to get source images

- Discontinuities at cube-face boundaries

Reflection Mapping – Cube

▷ From the point of view of the reflector:

- – Draw each of the 6 on-axis views to separate faces of the cube map

- – Be sure to pick a convenient "space" to draw in so that the reflection map can be used

  - – Probably align the axes of the cube map to the world-space

Reflection Mapping – Paraboloid

▷ View of environment as reflected by a convex parabolic mirror

- The *outside* of a satellite dish
- Reflects 180° of the environment
    - Capture 360° by using two maps
    - Known as dual paraboloid
- Fairly similar to a hemispherical reflection map

Reflection Mapping – Paraboloid

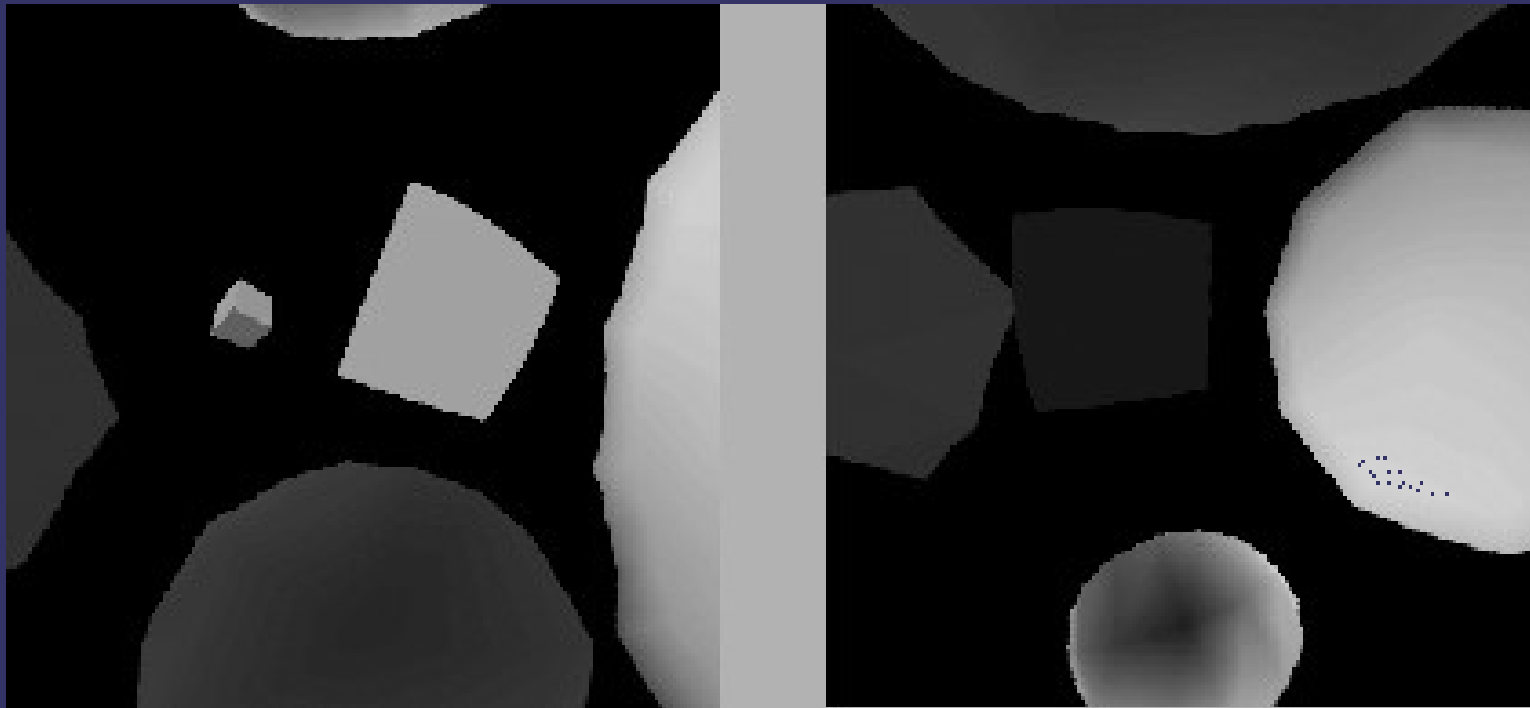⇨ Easily convert reflection vector to 2D texture coordinate for paraboloid map:

$$\begin{pmatrix} s \\ t \\ 1 \\ 1 \end{pmatrix} = \mathbf{A} \cdot \mathbf{P} \cdot \mathbf{S} \cdot \mathbf{M}_n^T \cdot \mathbf{r}^T$$

$$\mathbf{A} = \begin{vmatrix} \frac{1}{2} & 0 & 0 & \frac{1}{2} \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}, \mathbf{P} = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \end{vmatrix}, \mathbf{S} = \begin{vmatrix} -1 & 0 & 0 & \mathbf{d}_x \\ 0 & -1 & 0 & \mathbf{d}_y \\ 0 & 0 & 1 & \mathbf{d}_z \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

- $\mathbf{d}$ is the view direction vector
  - { 0 0 1 } or { 0 0 -1 } depending on the viewing direction
- $\mathbf{M}_n$ is the transformation matrix for normals

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Reflection Mapping – Paraboloid

Reflection Mapping – Paraboloid

⇨ From view point of reflector:
- Draw two images
- Transform vertexes as usual but:
  - Divide x, y, and z by w
    - Call the magnitude of this vector l
  - Normalize and divide x and y by (z + 1)
  - Set z to l remapped to view volume
    - Usual [0, 1] mapping based on near / far
  - Set w to 1.0

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References

http://opengl.org/resources/code/samples/sig99/advanced99/notes/node184.html

Jason Zink. "Dual Paraboloid Mapping in the Vertex Shader." GameDev.net, 1996. http://www.gamedev.net/reference/articles/article2308.asp

Wolfgang Heidrich and Hans-Peter Seidel. "View-independent environment maps." In *Proceedings of the SIGGRAPH/Eurographics Worksjhop on Graphics Hardware*, 1998. http://www.cs.ubc.ca/~heidrich/Papers/GH.98.pdf

Michael Ashikhmin and Abhijeet Ghosh. "Simple Blurry Reflections with Environment Maps." Journal of Graphics Tools, 7(4): 3-8, 2002. http://people.ict.usc.edu/~ghosh/papers.html

R. Ramamoorthi and P. Hanraham. "An Efficient Representation for Irradiance Environment Maps." In *Proceedings of SIGGRAPH 2001, Computer Graphics Proceedings*, Annual Conference Series, edited by E. Fiume, pp. 497–500, Reading, MA: Addison-Wesley, 2001. http://www-graphics.stanford.edu/papers/envmap/

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Reflection Maps as Lights

▷ Just like reflection mapping:

- Render the "light" into the reflection map
- The part of the reflection map that isn't the light is black
  - Can put multiple lights in one reflection map

Reflection Maps as Lights

▷ What is the limitation of this simple approach?

Reflection Maps as Lights

▷ What is the limitation of this simple approach?

- Really only works for perfectly mirror-like surfaces

    - Surfaces where the specular exponent approaches ∞

- Essentially creates an aliasing problem

    - Only one sample is taken from the environment

Reflection Maps as Lights

⇨ If under-sampling is the problem, how can we fix it?

Reflection Maps as Lights

⇨ If under-sampling is the problem, how can we fix it?

- Obvious answer: take more samples
- Filter the samples together
  - The lighting equation supplies the sample weights

Reflection Maps as Lights

⇨ What is the problem with this technique?

Reflection Maps as Lights

▷ What is the problem with this technique?

 – Taking enough samples to get good results is slow

 – Taking few enough samples to be fast gives poor results

▷ *Remind* you of anything?

 – And what was the solution there?

Reflection Maps as Lights

⇨ Just like texture minification!

- The answer there was to create pre-filtered versions of the texture called mipmaps

⇨ Create new reflection maps:

- Each texel in the new map is created from *all* of the texels in the old map filtered using weights from the lighting equation

- This is expensive, but it only has to be done once... and that can be off-line

Reflection Maps as Lights

⇨ Notes / caveats:

- The new reflection map only includes the specular component

- Must be generated with a constant $\mathbf{v}$, so the resulting reflection map is view-dependent

- Can create a second map for diffuse lighting

  - Use the diffuse lighting equation

  - Use the surface normal instead of the reflection vector

  - This type of reflection map is called an *irradiance map*

Changing Specular

Far away

Closer

Very close

Changing Specular

Large specular highlight

Smaller specular highlight

No highlight

Changing Specular

⇨ What's happening?

Changing Specular

▷ What's happening?

- – We know 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 seems to depend on the relative orientation of the reflection vector and the surface

    - – Our current lighting model doesn't account for this!

Changing Specular
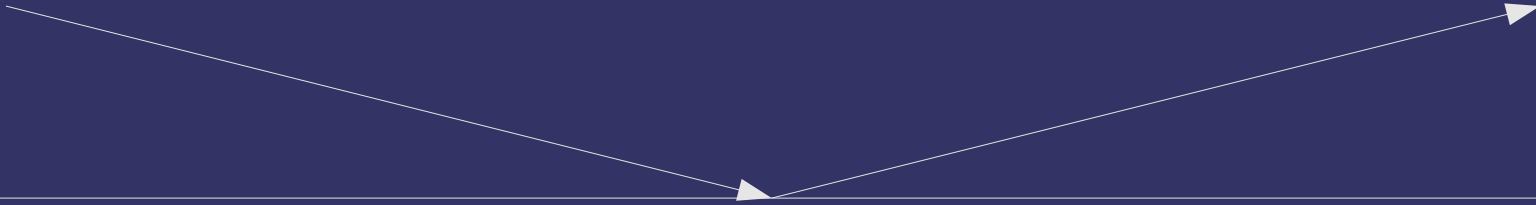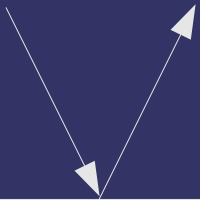
Large specular highlight

Smaller specular highlight

No specular highlight

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

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

Wave Theory – Refraction

▷ When light leaves one material and enters another, it changes direction

   – At the *interface* the speed changes, and the light bends

r

q

n

Air

Water

l
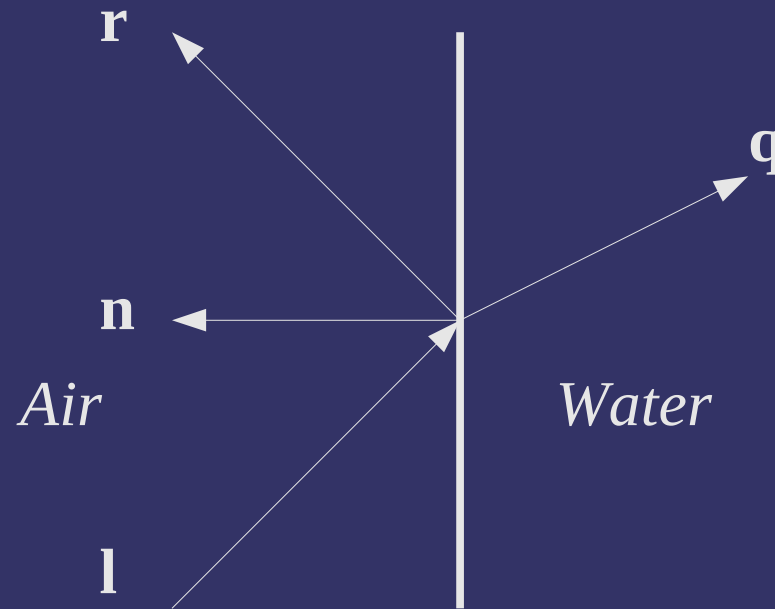
Wave Theory – Refraction

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

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

Reflection vs. Refraction
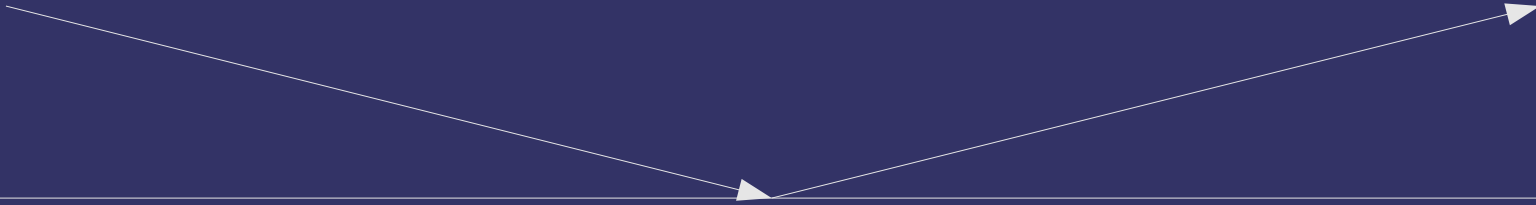
~~Large specular highlight~~
Lots of reflection
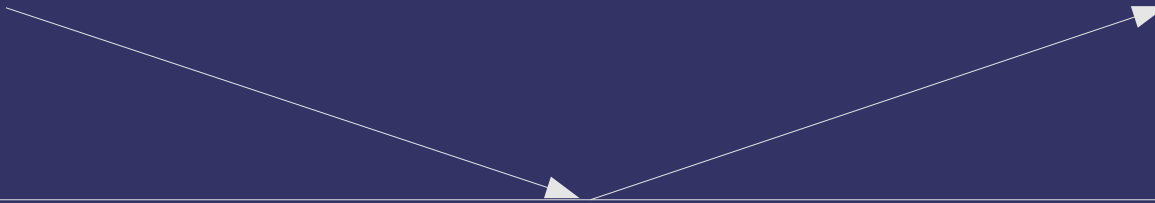
~~Smaller specular highlight~~
Some reflection
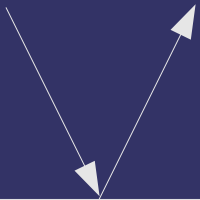
~~No specular highlight~~
No reflection

Reflection Math

▷ The fraction of light reflected, $R(\theta)$, is:

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

Where:

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

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

- n_i is the refractive index of the first material

- n_t is the refractive index of the second material

- θ is the angle between the surface normal and the light vector

- Sometimes $R(\theta)$ is written as F

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Reflection Math

▷ Yewouch! That math is complex and expensive

▷ A good approximation exists:

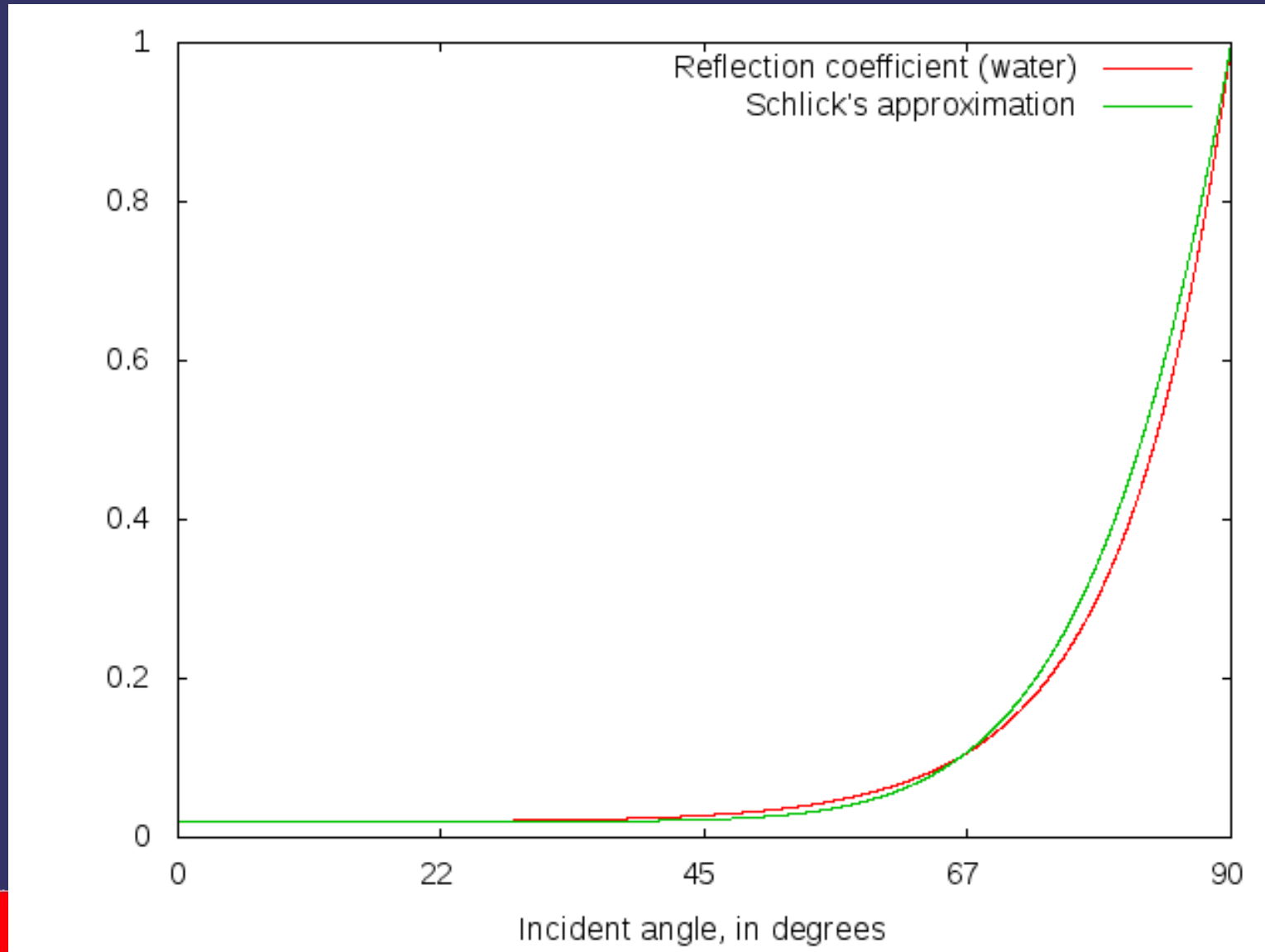$$R(\theta) = R_0 + (1 - R_0)(1 - \cos\theta)^5$$

  – 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
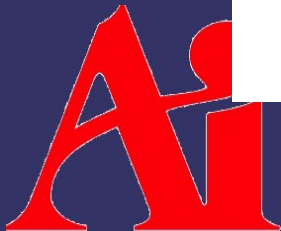
  – Known as "Schlick's approximation"

Reflection Math

Chart legend: Reflection coefficient (water), Schlick's approximation. Y-axis from 0 to 1. X-axis "Incident angle, in degrees" from 0 to 90 (22, 45, 67, 90 marked).

Reflection Math

Reflection Math

Reflection Math

Poor approximation
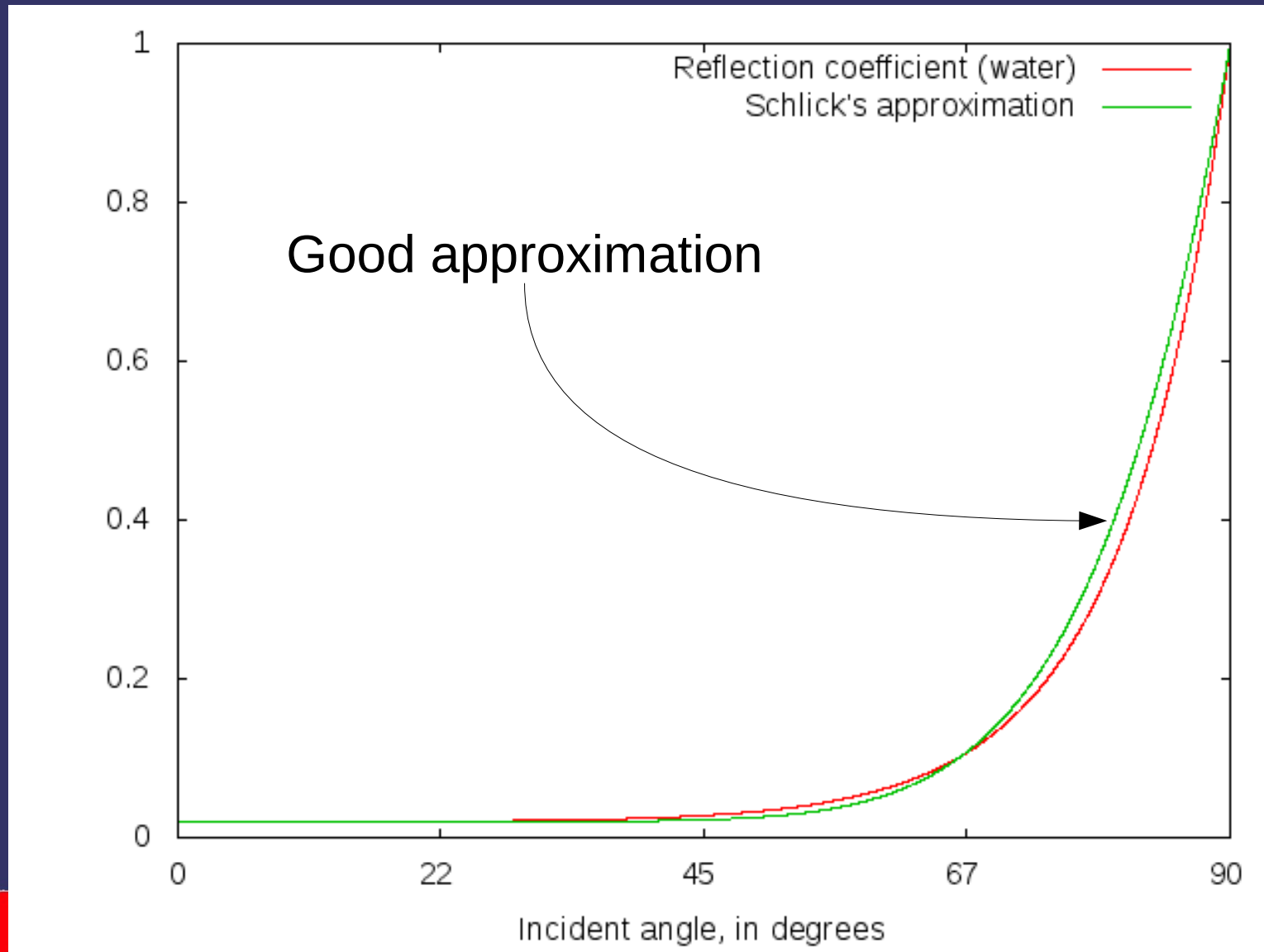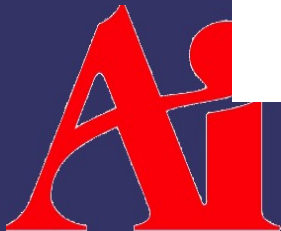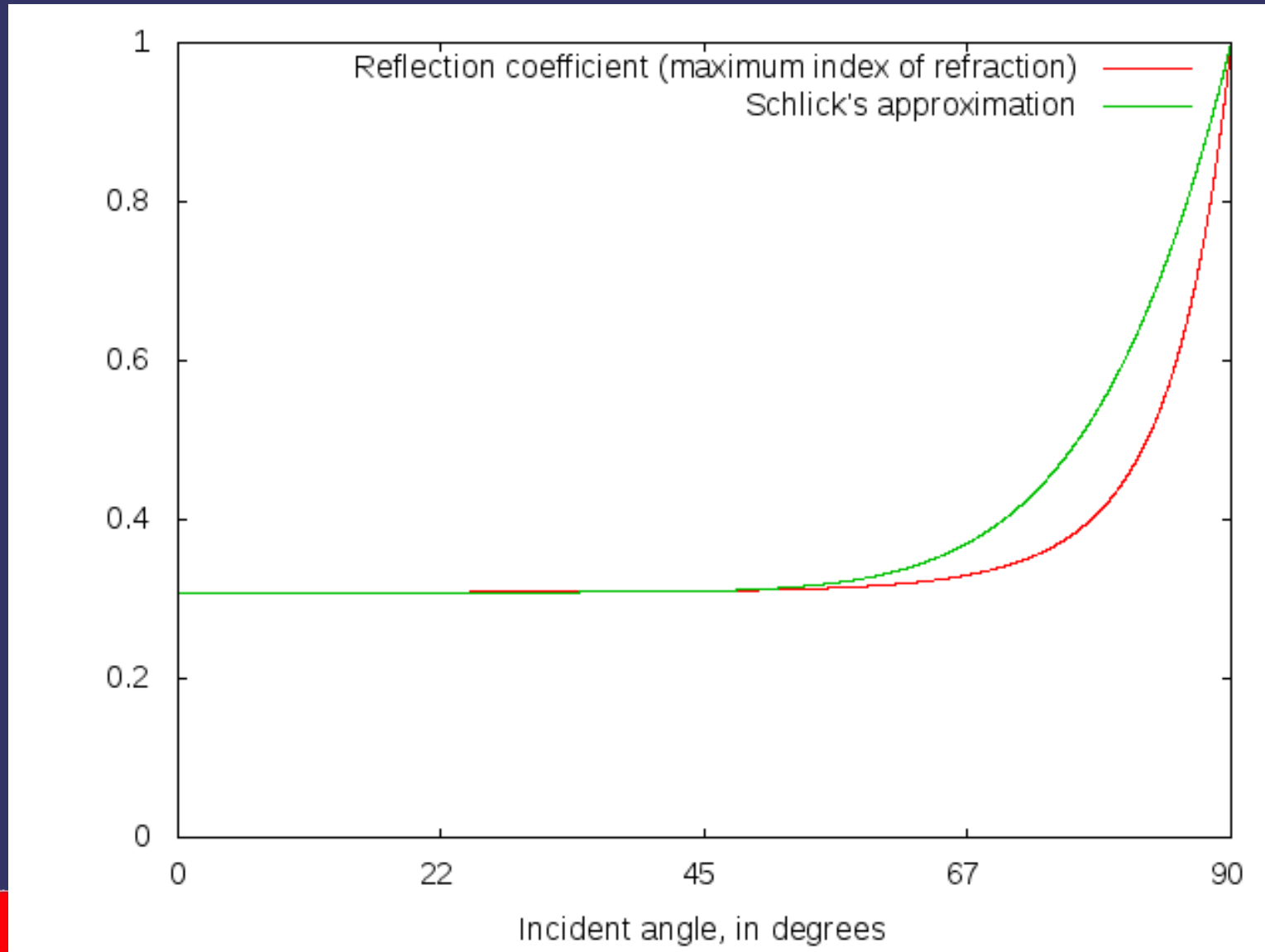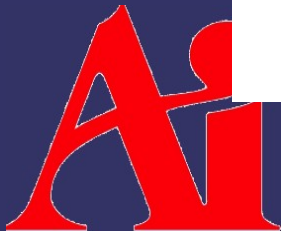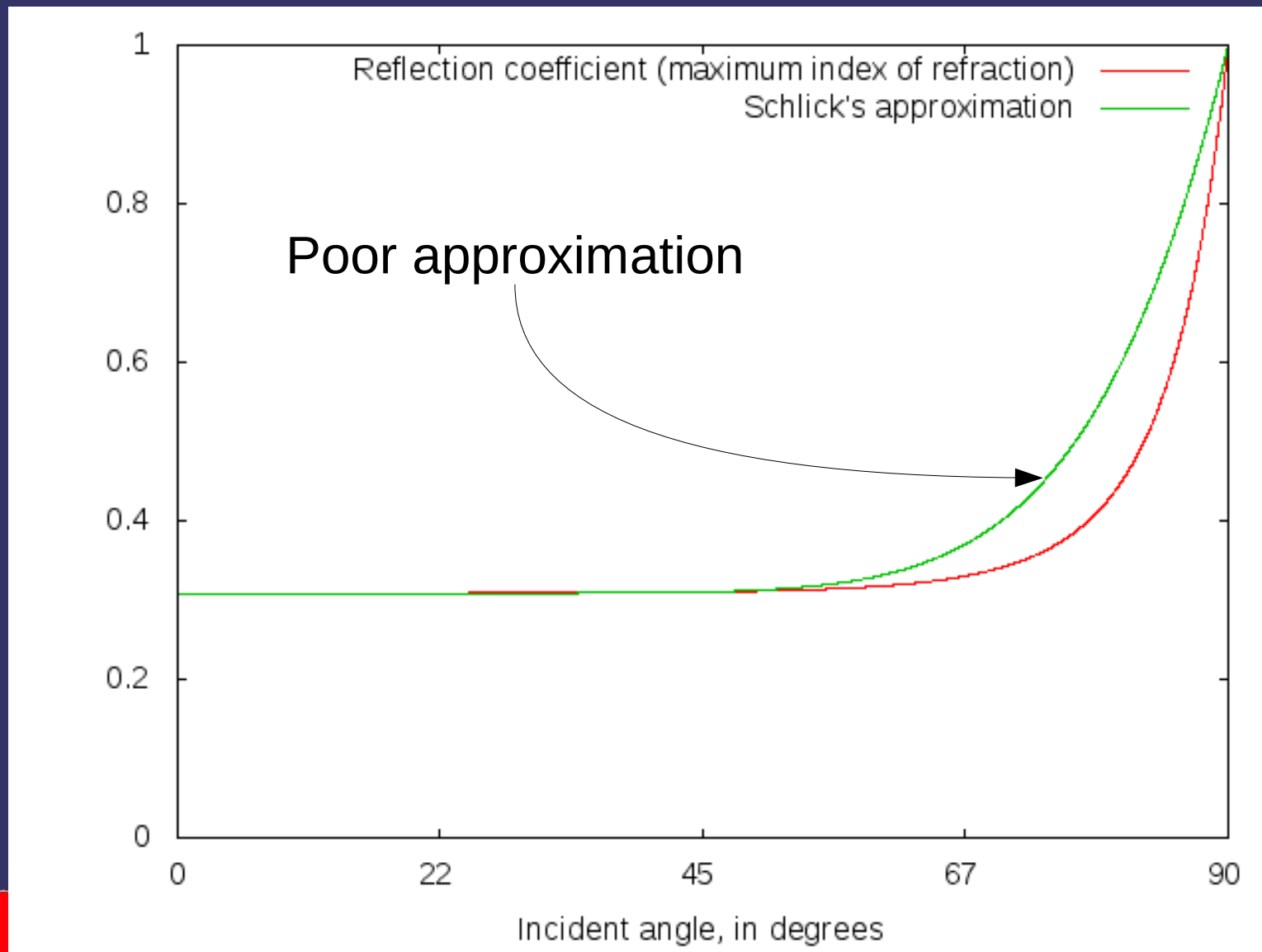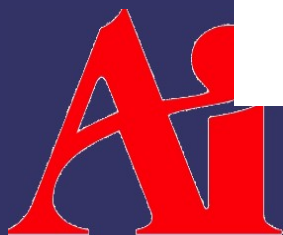
Fresnel Reflection in Lighting

▷ 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

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...

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...

▷ BRDFs, part 1
  – Common ideas and terminology
  – Cook-Torrance BRDF
  – Micro-facet based BRDFs

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