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

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

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

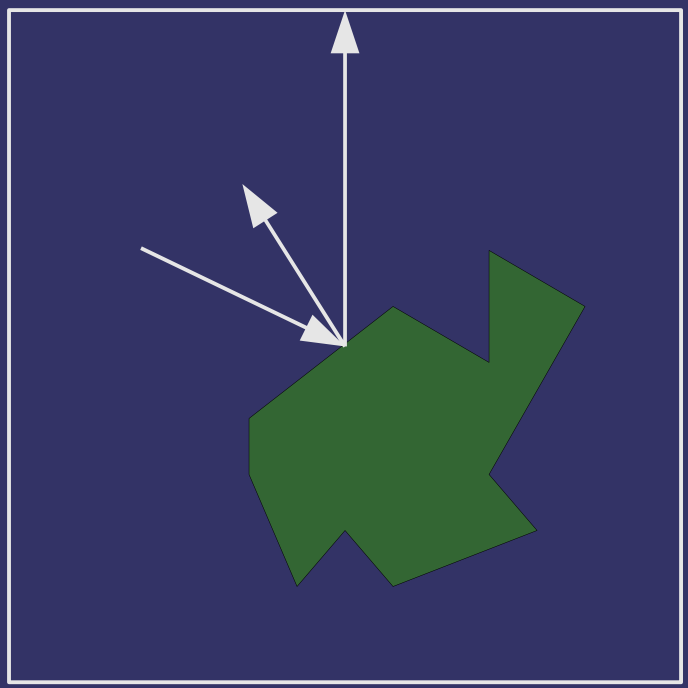
`GL_EXT_framebuffer_object` and related extension specifications:

- 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

Reflection Mapping

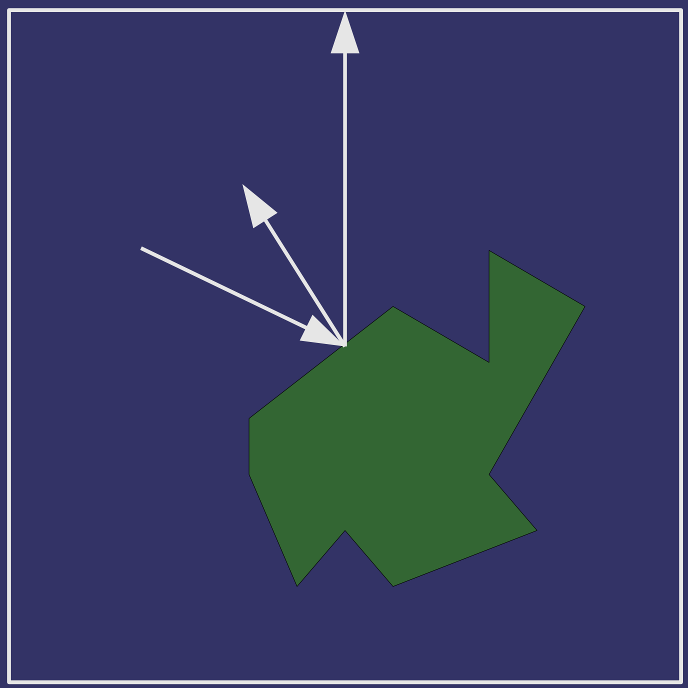
- Forms of reflection mapping are classified by the shape used to simulate the environment
  - Cylindrical
  - Hemispherical
  - Spherical
  - Cube
  - Dual-paraboloid

Reflection Mapping – Cube



- Extend $\mathbf{r}$ 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

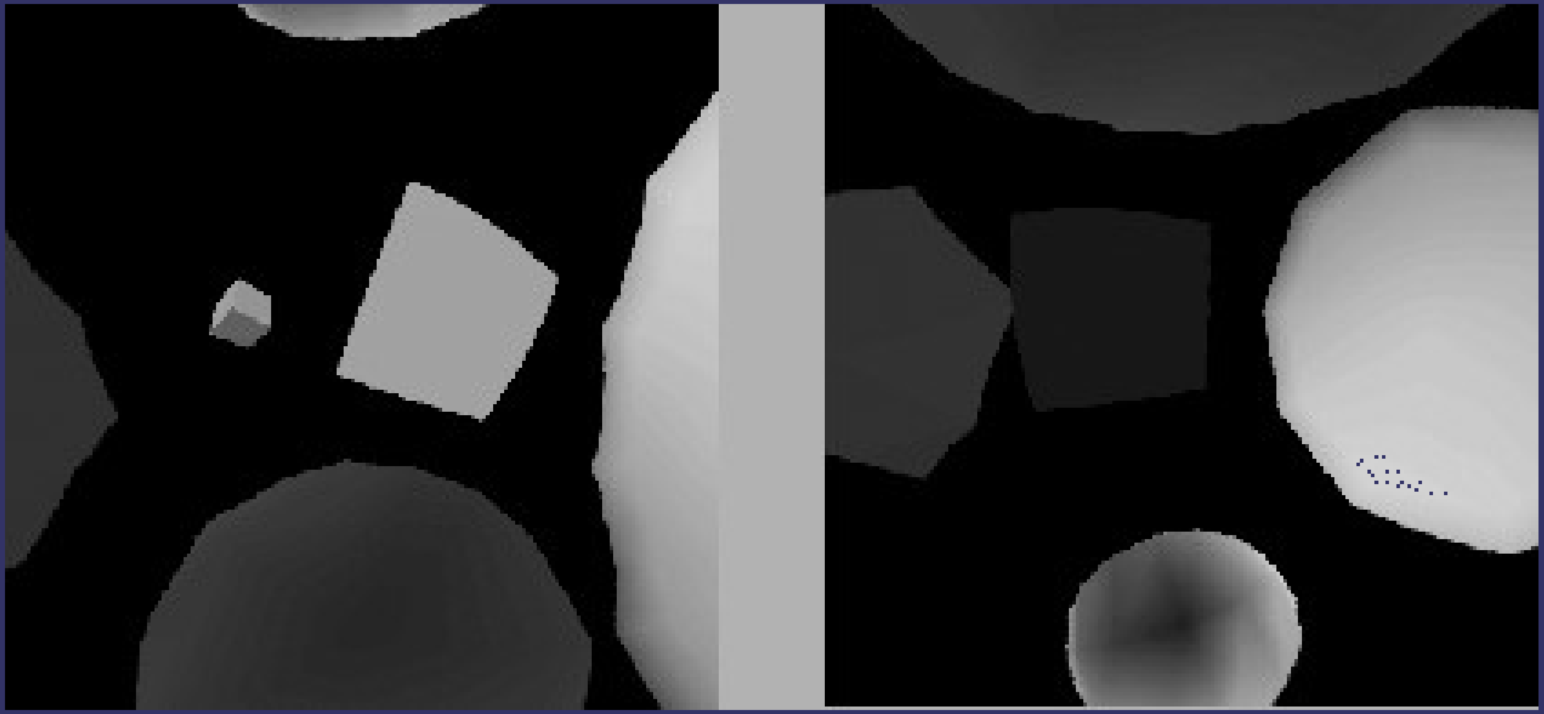
- Easily convert reflection vector to 2D texture coordinate for paraboloid map:

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

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

  - $\mathbf{d}$ 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

Reflection Mapping – Paraboloid



Original image from
http://opengl.org/resources/code/samples/sig99/advanced99/notes/node185.html

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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

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

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*

References

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/

Changing Specular

Far away

Closer

Very close

Changing Specular

Large specular highlight

Smaller specular highlight

No highlight

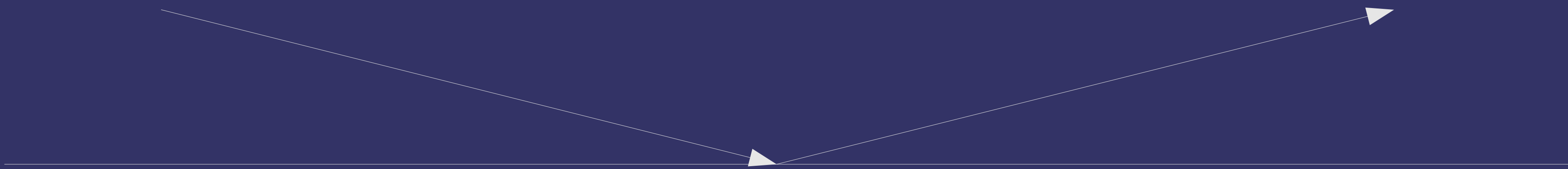
Changing Specular

- What's happening?

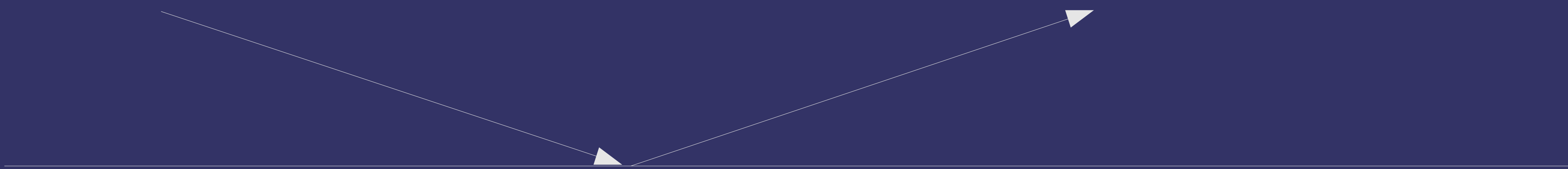
Changing Specular

- 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

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Fresnel Reflection

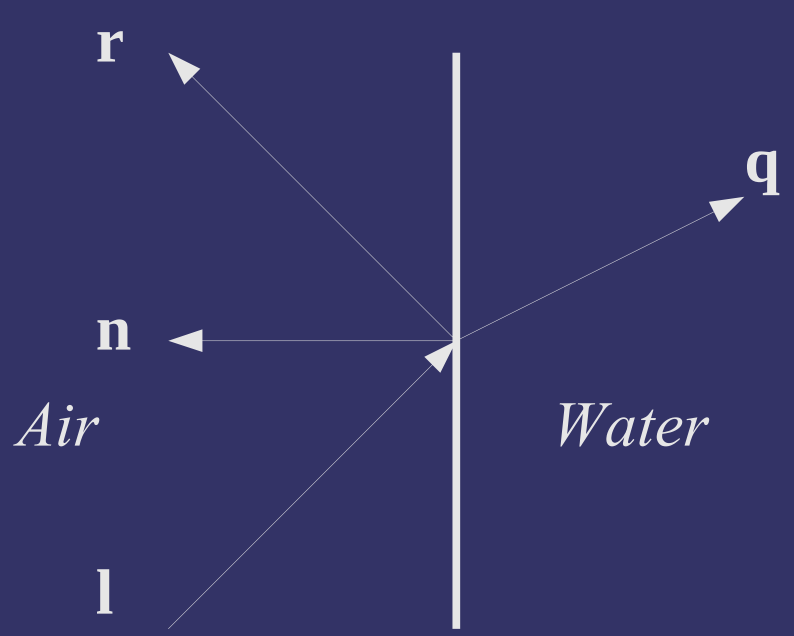
- Named after French physicist Augustin-Jean Fresnel
  - It's French... It's pronounced *fray-NELL*
- Light moves at different speeds through different materials
  - The ratio of the speed of light in a vacuum to the speed in a particular material is the *refractive index* of that material
  - Glass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

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



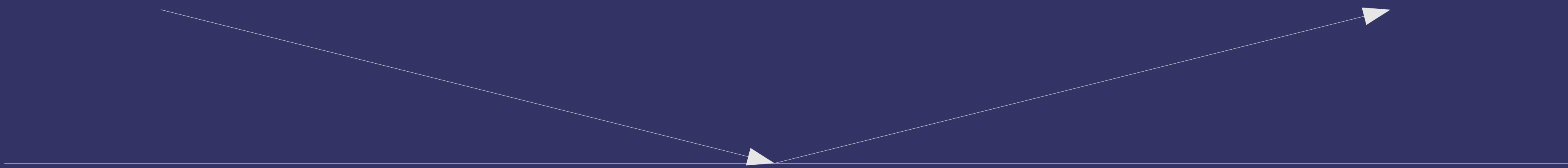
Wave Theory – Refraction

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, $\mathrm{R}(\theta)$, 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 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 $\mathrm{R}(\theta)$ is written as F

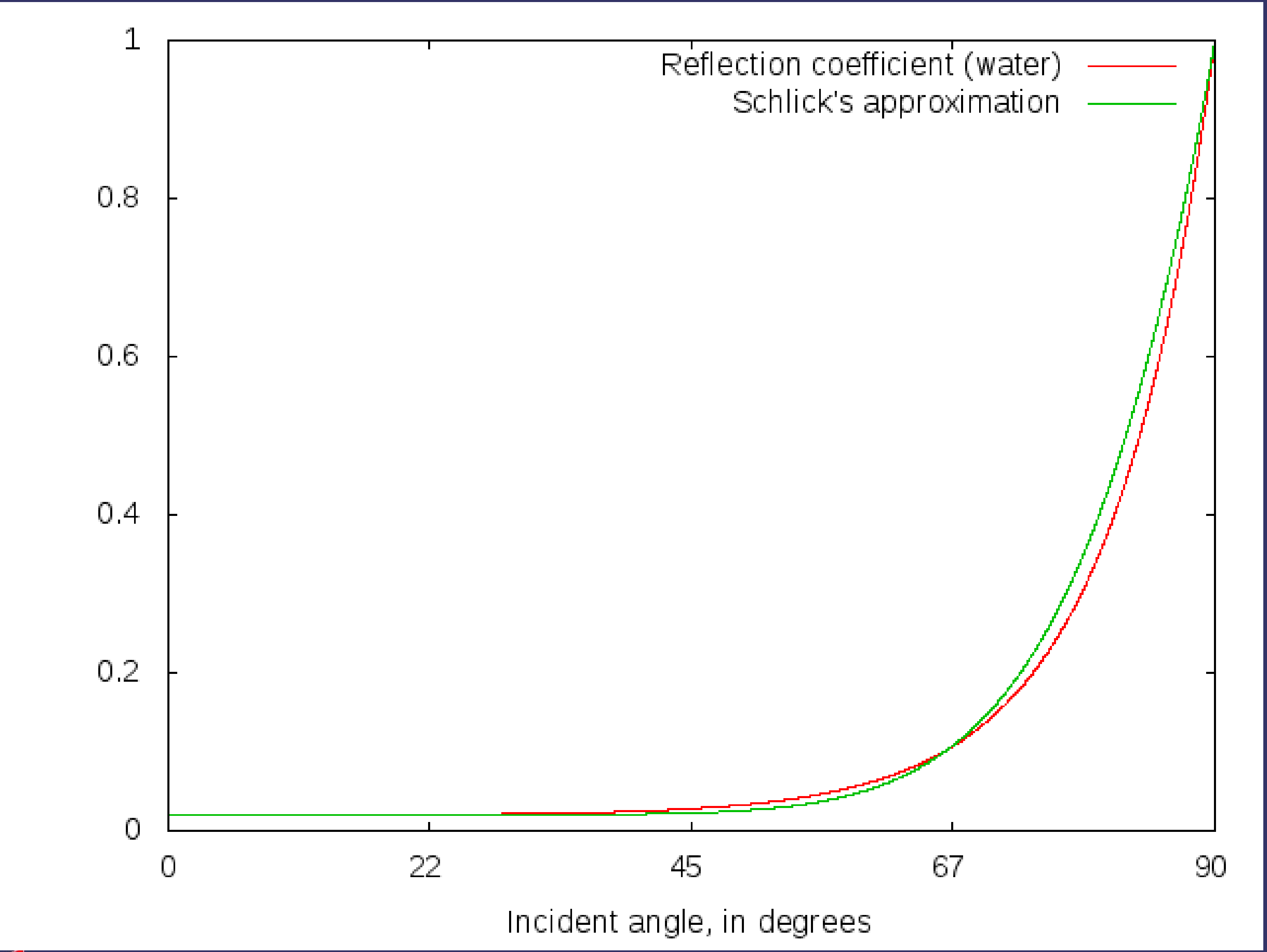
Reflection Math

- 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



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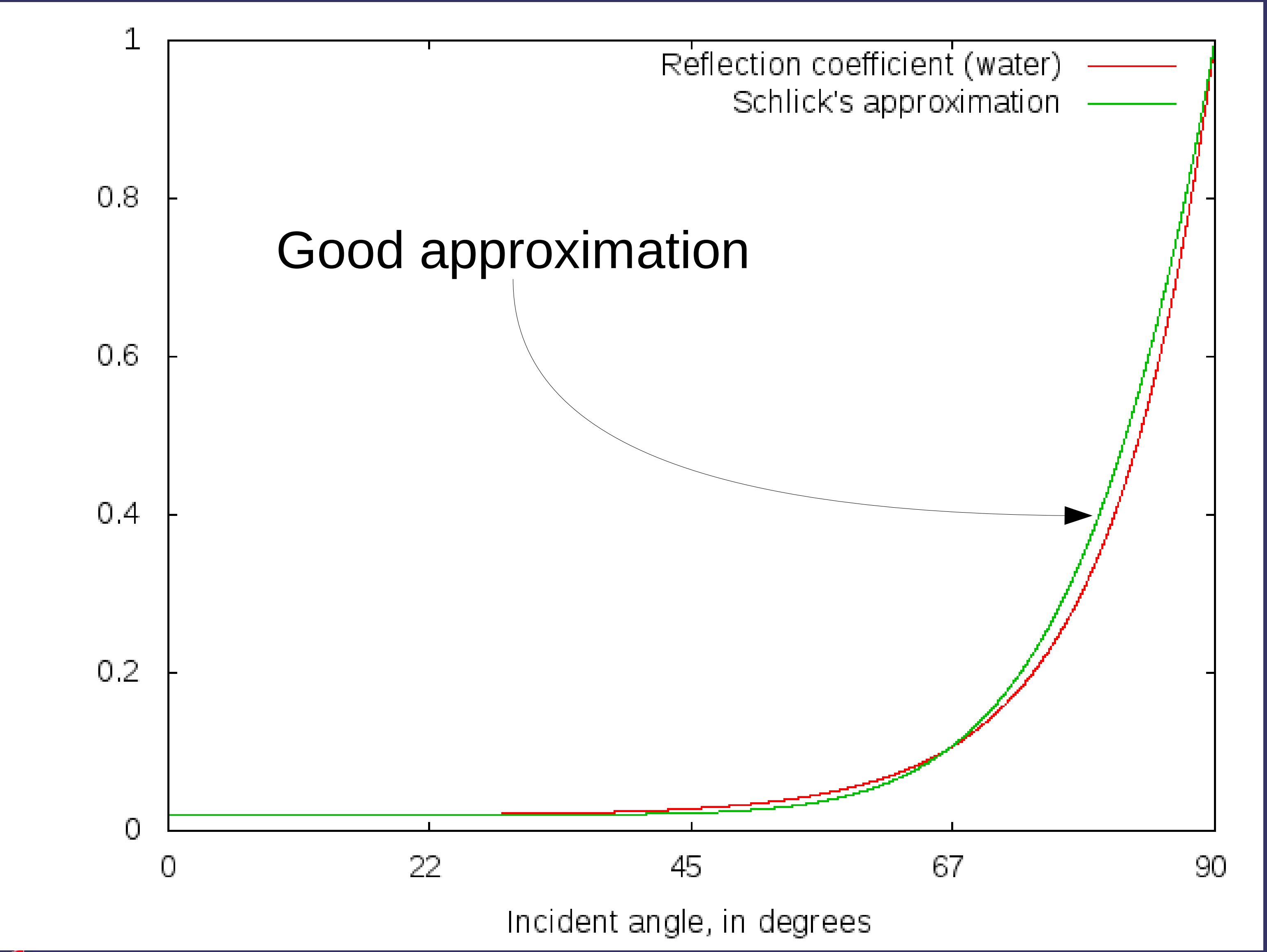
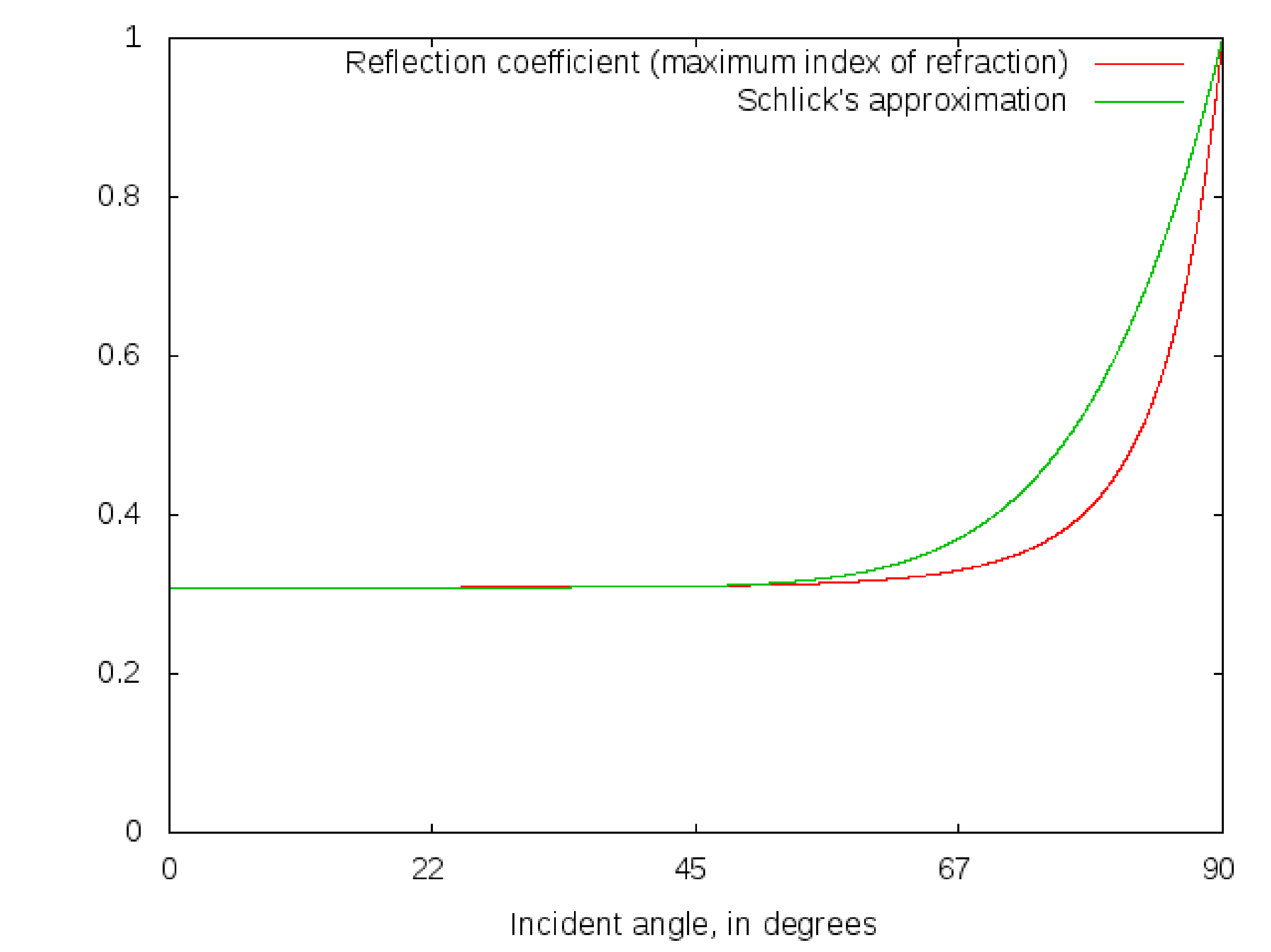
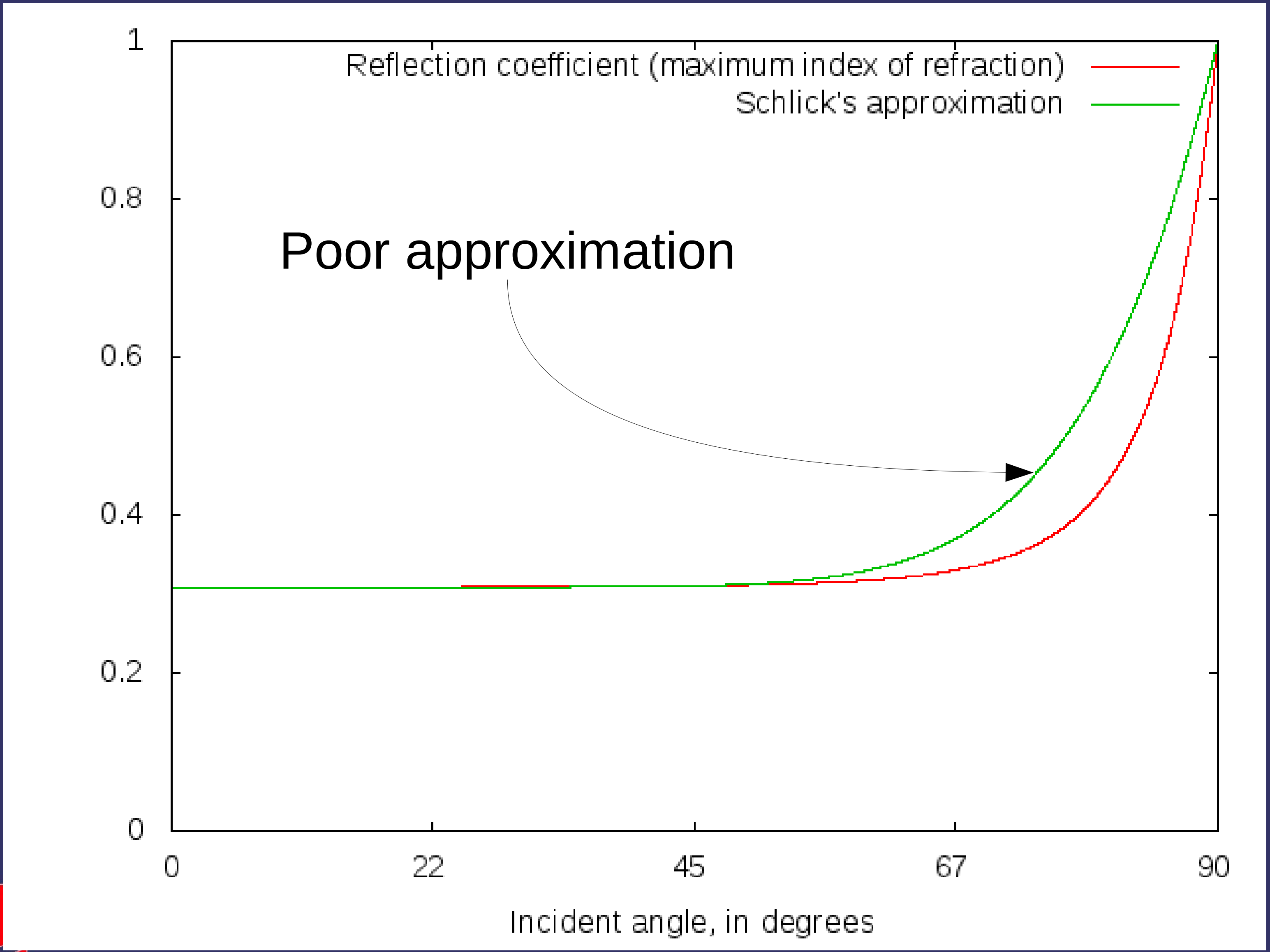
Reflection Math



Reflection Math



Reflection Math



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>”

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/

Next week...

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

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