CSE 167:
Introduction to Computer Graphics
Lecture #7: Lights

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Announcements

- Thursday in-class: Midterm
  - Can include material up to and including today's lecture
- Project 3 late grading deadline this Friday
  - Grading starts at 12:30pm, ends at 1:30pm

Lecture Overview

- OpenGL Light Sources
  - Directional Lights
  - Point Lights
  - Spot Lights

Light Sources

- Real light sources can have complex properties
  - Geometric area over which light is produced
  - Anisotropy (directionally dependent)
  - Reflective surfaces act as light sources (indirect light)







- OpenGL uses a drastically simplified model to allow real-time rendering

OpenGL Light Sources

- At each point on surfaces we need to know
  - Direction of incoming light (the $\mathbf{L}$ vector)
  - Intensity of incoming light (the c_l values)
- Standard light sources in OpenGL
  - Directional: from a specific direction
  - Point light source: from a specific point
  - Spotlight: from a specific point with intensity that depends on direction

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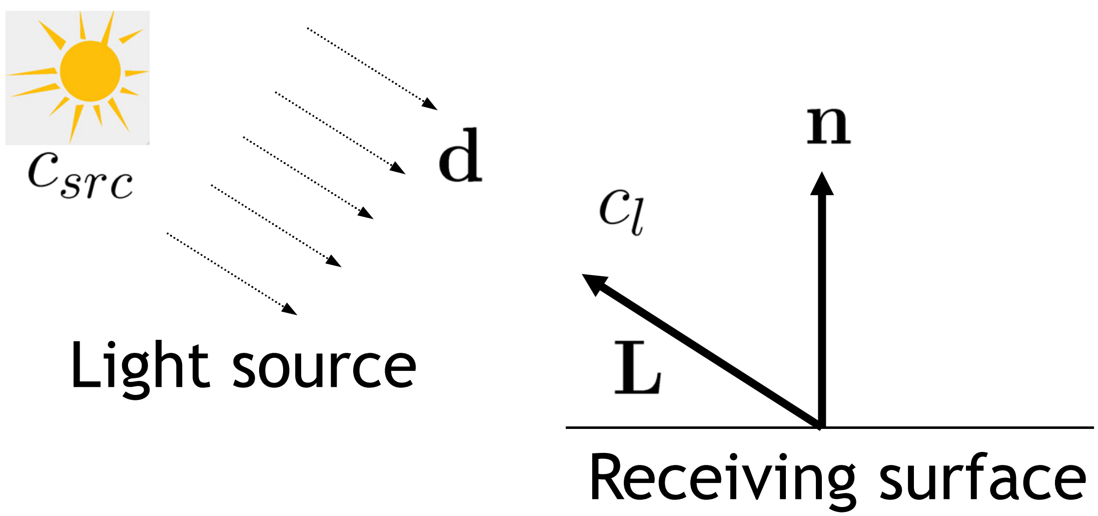
Directional Light

- Light from a distant source
  - Light rays are parallel
  - Direction and intensity are the same everywhere
  - As if the source were infinitely far away
  - Good approximation of sunlight
- Specified by a unit length direction vector, and a color



$$\mathbf{L} = -\mathbf{d}$$

$$c_l = c_{src}$$

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Point Lights

- Similar to light bulbs
- Infinitely small point radiates light equally in all directions
  - Light vector varies across receiving surface
  - What is light intensity over distance proportional to?
  - Intensity drops off proportionally to the inverse square of the distance from the light
    - Reason for inverse square falloff:
      Surface area A of sphere:
      $A = 4 \pi r^2$

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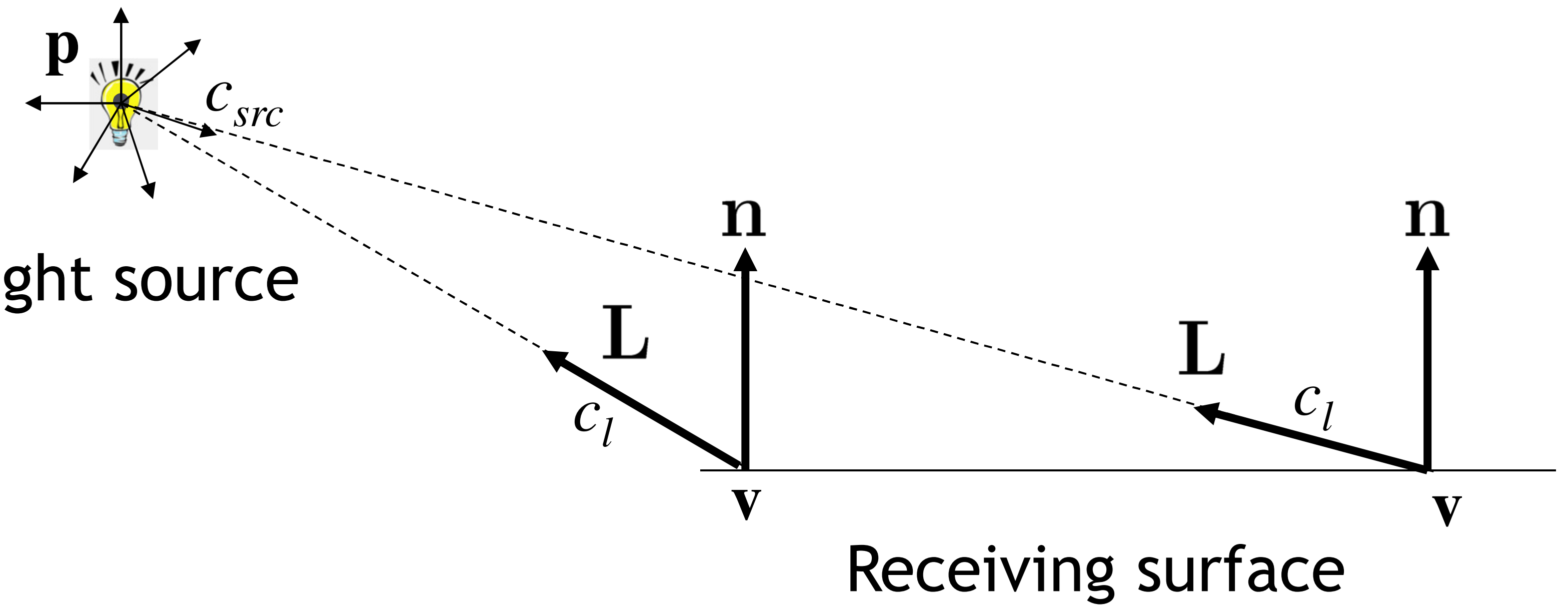
Point Lights in Theory



At any point v on the surface:

$$\mathbf{L} = \frac{\mathbf{p} - \mathbf{v}}{\|\mathbf{p} - \mathbf{v}\|}$$

$$c_l = \frac{c_{src}}{\|\mathbf{p} - \mathbf{v}\|^2}$$

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Point Lights in OpenGL

- OpenGL model for distance attenuation:

$$c_l = \frac{c_{src}}{k_c + k_l\,|\mathbf{p}-\mathbf{v}| + k_q\,|\mathbf{p}-\mathbf{v}|^2}$$

- Attenuation parameters:
  - k_c = constant attenuation, default: 1
  - k_l = linear attenuation, default: 0
  - k_q = quadratic attenuation, default: 0
- Default: no attenuation: $c_l = c_{src}$
- Change attenuation parameters with:
  - GL_CONSTANT_ATTENUATION
  - GL_LINEAR_ATTENUATION
  - GL_QUADRATIC_ATTENUATION

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Spotlights

- Like point source, but intensity depends on direction

Parameters

- Position: location of light source
- Spot direction: center axis of light source
- Falloff parameters:
  - Beam width (cone angle)
  - The way the light tapers off at the edges of the beam (cosine exponent)

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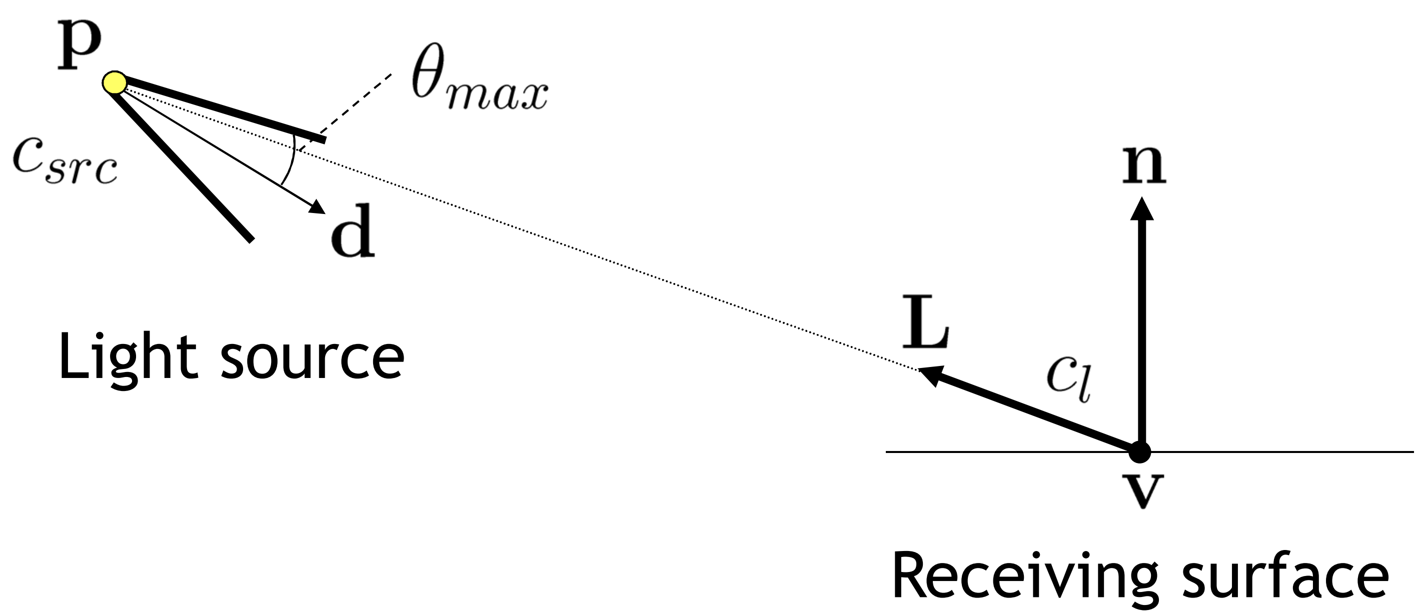
Spotlights

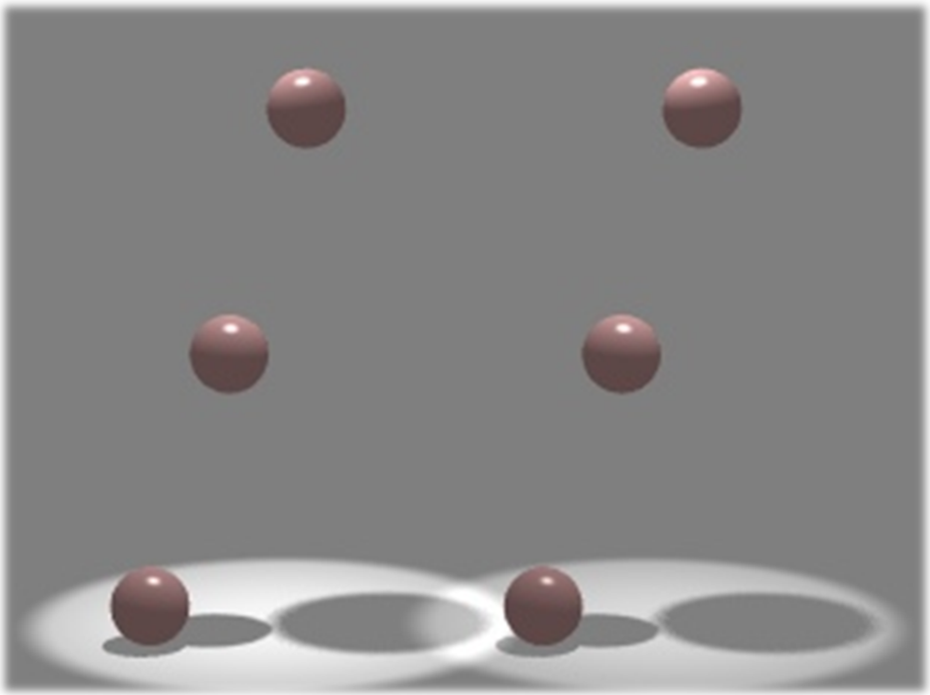


$$\mathbf{L} = \frac{\mathbf{p} - \mathbf{v}}{\|\mathbf{p} - \mathbf{v}\|}$$

$$c_l = \begin{cases} 0 & \text{if} \quad -\mathbf{L} \cdot \mathbf{d} \leq \cos(\theta_{max}) \\ c_{src} \, (-\mathbf{L} \cdot \mathbf{d})^f & \text{otherwise} \end{cases}$$

Spotlights

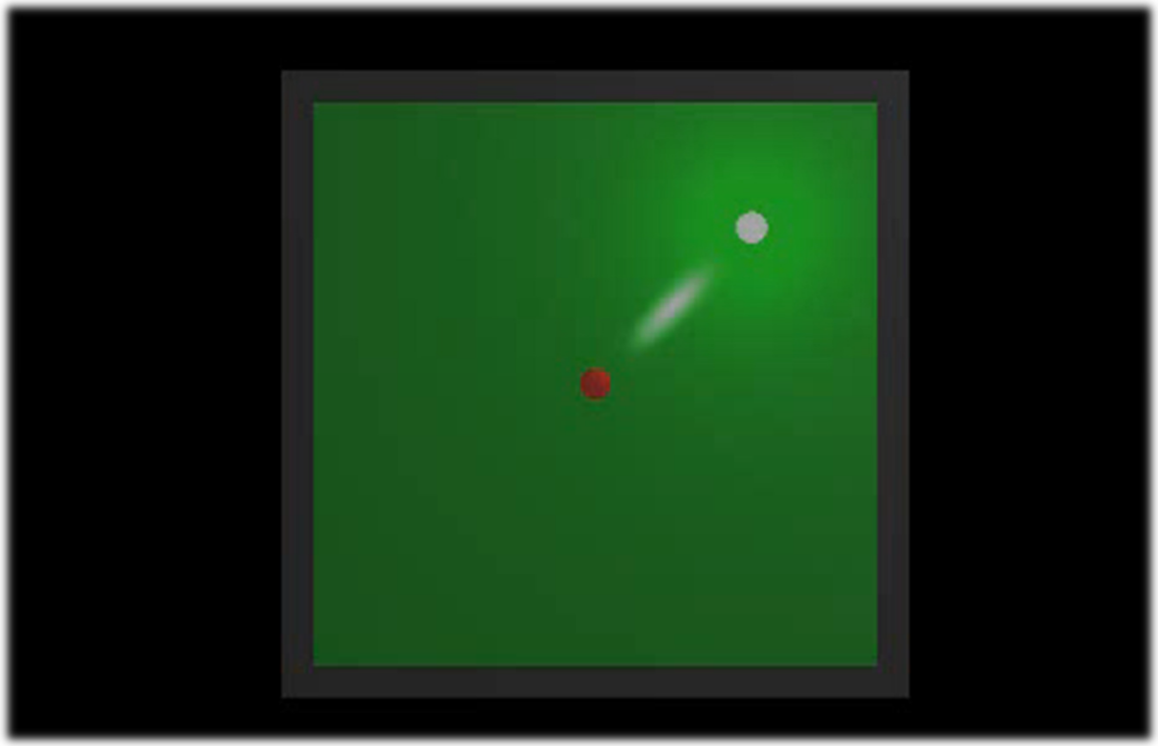
Photograph of real spotlight



Spotlights in OpenGL

Video

- C++ OpenGL Lesson on Basic Lighting
  - http://www.youtube.com/watch?v=g_0yV7jZvGg



Lecture Overview

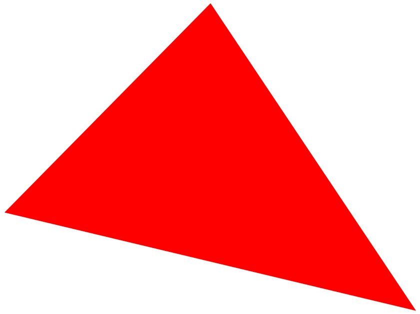
- Types of Geometry Shading
- Shading in OpenGL
  - Fixed-Function Shading
  - Programmable Shaders
    - Vertex Programs
    - Fragment Programs
    - GLSL

Types of Shading

- Per-triangle
- Per-vertex
- Per-pixel

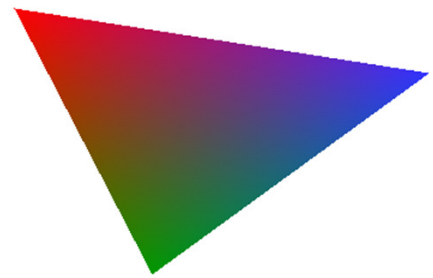
Per-Triangle Shading

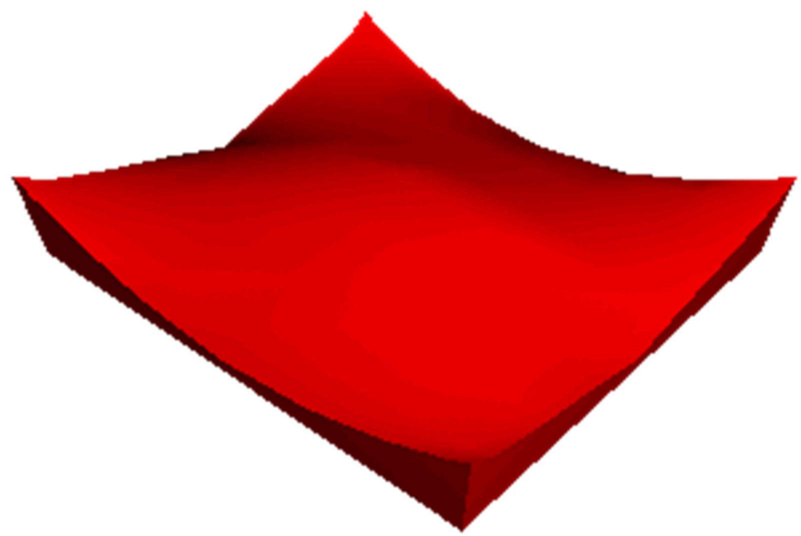
- A.k.a. *flat shading*
- Evaluate shading once per triangle
- Advantage
  - Fast
- Disadvantage
  - Faceted appearance



Per-Vertex Shading

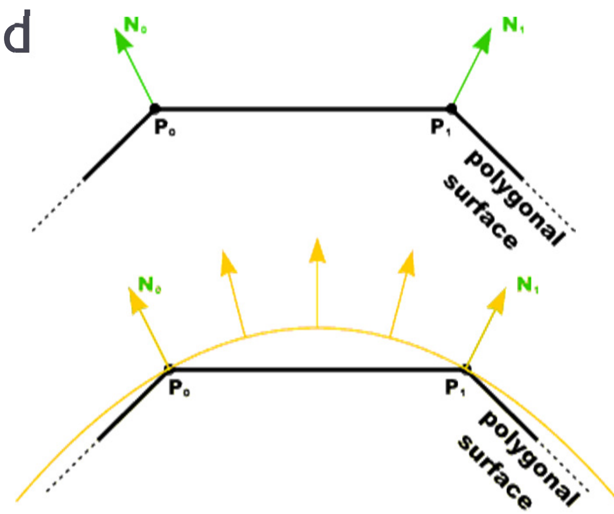
- Known as *Gouraud shading* (Henri Gouraud, 1971)
- Interpolates vertex colors across triangles
- Advantages
  - Fast
  - Smoother surface appearance than with flat shading
- Disadvantage
  - Problems with small highlights





Per-Pixel Shading

- A.k.a. *Phong Interpolation* (not to be confused with *Phong Illumination Model*)
  - Rasterizer interpolates <u>normals</u> (instead of colors) across triangles
  - Illumination model is evaluated at each pixel
  - Simulates shading with normals of a curved surface
- Advantage
  - Higher quality than Gouraud shading
- Disadvantage
  - Slow



Source: Penny Rheingans, UMBC

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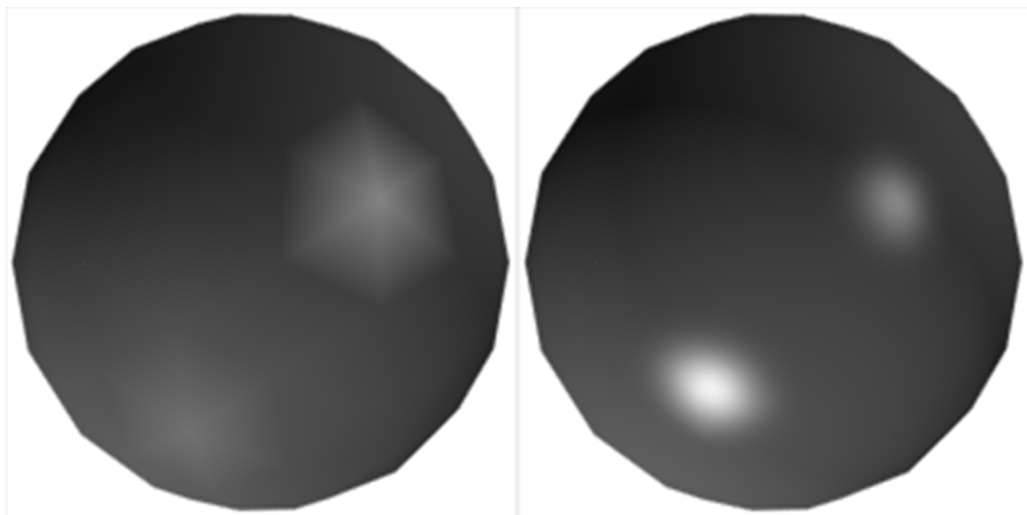
Gouraud vs. Per-Pixel Shading

- Gouraud shading has problems with highlights when polygons are large
- More triangles improve the result, but reduce frame rate



Gouraud Per-Pixel

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Shading with Fixed-Function Pipeline

- Fixed-function pipeline only allows Gouraud (per-vertex) shading
- We need to provide a normal vector for each vertex
- Shading is performed in camera space
  - Position and direction of light sources are transformed by GL_MODELVIEW matrix
- If light sources should be in object space:
  - Set GL_MODELVIEW to desired object-to-camera transformation
  - Use object space coordinates for light positions
- More information:
  - http://glprogramming.com/red/chapter05.html
  - http://www.falloutsoftware.com/tutorials/gl/gl8.htm

Tips for Transforming Normals

- If you need to (manually) transform geometry by a transformation matrix **M,** which includes shearing or scaling:
  - Transforming the normals with **M** will not work: transformed normals are no longer perpendicular to surfaces
- Solution: transform the normals differently:
  - Either transform the end points of the normal vectors separately
  - Or transform normals with
- OpenGL does this automa M^{-1^T} the following command is used:
  - glEnable(GL_NORMALIZE)
- More details on-line at:
  - http://www.oocities.com/vmelkon/transformingnormals.html

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Programmable Shaders in OpenGL

- Initially, OpenGL only had a fixed-function pipeline for shading
- Programmers wanted more flexibility, similar to programmable shaders in raytracing software (term "shader" first introduced by Pixar in 1988)
- First shading languages came out in 2002:
  - **Cg** (C for Graphics, created by Nvidia)
  - **HLSL** (High Level Shader Language, created by Microsoft)
- They supported:
  - **Fragment shaders**: allowed per-pixel shading
  - **Vertex shaders**: allowed modification of geometry

Programmable Shaders in OpenGL

- OpenGL 2.0 supported the OpenGL Shading Language (GLSL) in 2003
- **Geometry shaders** were added in OpenGL 3.2
- **Tessellation shaders** were added in OpenGL 4.0
- Programmable shaders allow real-time:
  Shadows, environment mapping, per-pixel lighting, bump mapping, parallax bump mapping, HDR, etc.

Demo

- NVIDIA Froggy
  - http://www.nvidia.com/coolstuff/demos#!/froggy
  - Bump mapping shader for Froggy's skin
  - Physically-based lighting model simulating sub-surface scattering
  - Supersampling for scene anti-aliasing
  - Raytracing shader for irises to simulate refraction for wet and shiny eyes
  - Dynamically-generated lights and shadows