Chapter 6 - Light, Materials, Appearance

- Types of light in nature and in CG
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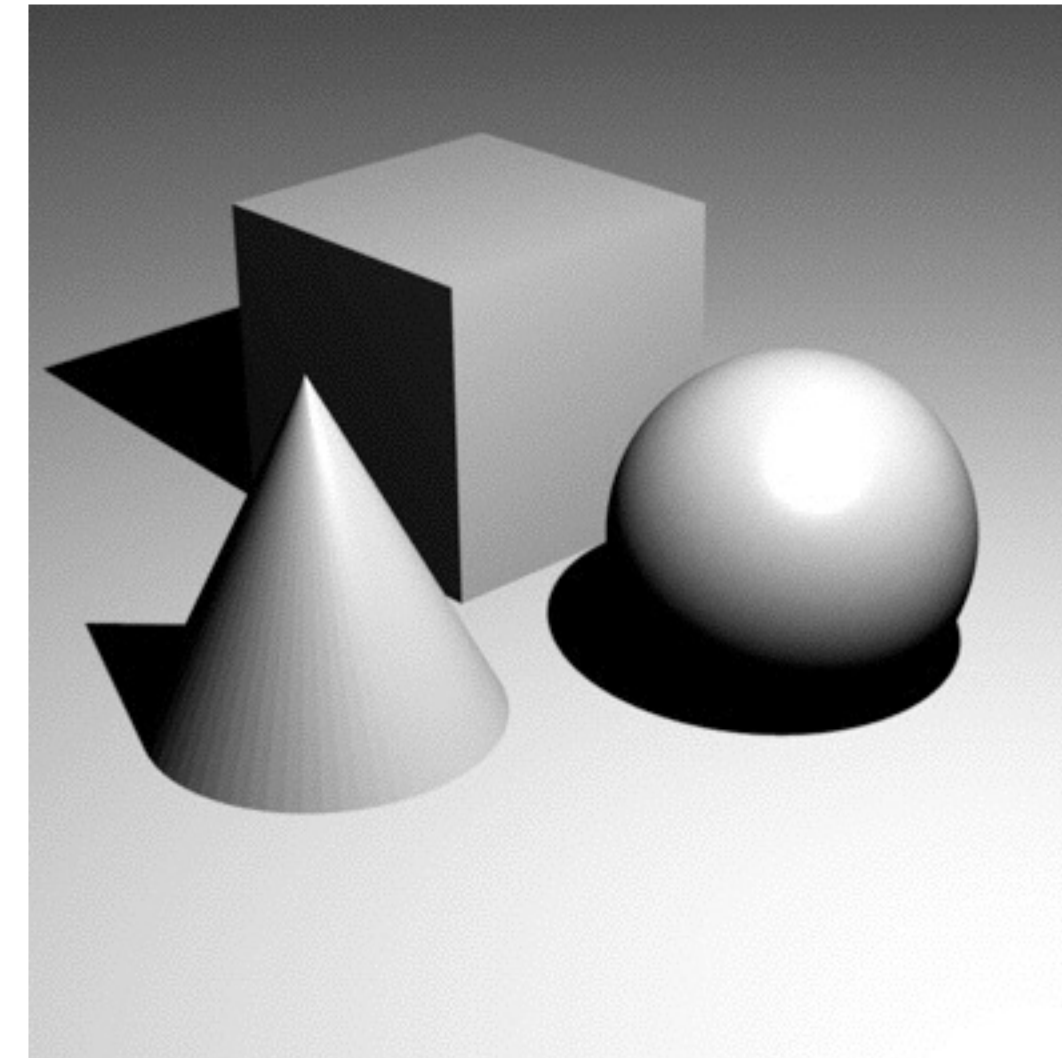
Light in Nature (Physics Refresher)

http://www.lebjournal.com/newz/wp-content/candle-light-photography.jpg

- Can be described as a electromagnetic wave
- Can also be described as a stream of photons
- Intensity drops with distance from the source
  - how?
  - ____________________________________
- Monochromatic (1 color) light has 1 frequency
- White light is a mixture of many frequencies
- Can be simulated for the human eye by adding Red, Green and Blue

- The human eye can discriminate a dynamic range of 1:2^{30} with adaptation or 1:2^{16} without [Seetzen et al., „High dynamic range display systems“, ACM Siggraph 2004]
- Film, digital cameras, and computer screens can only deal with less!

Point Light Sources



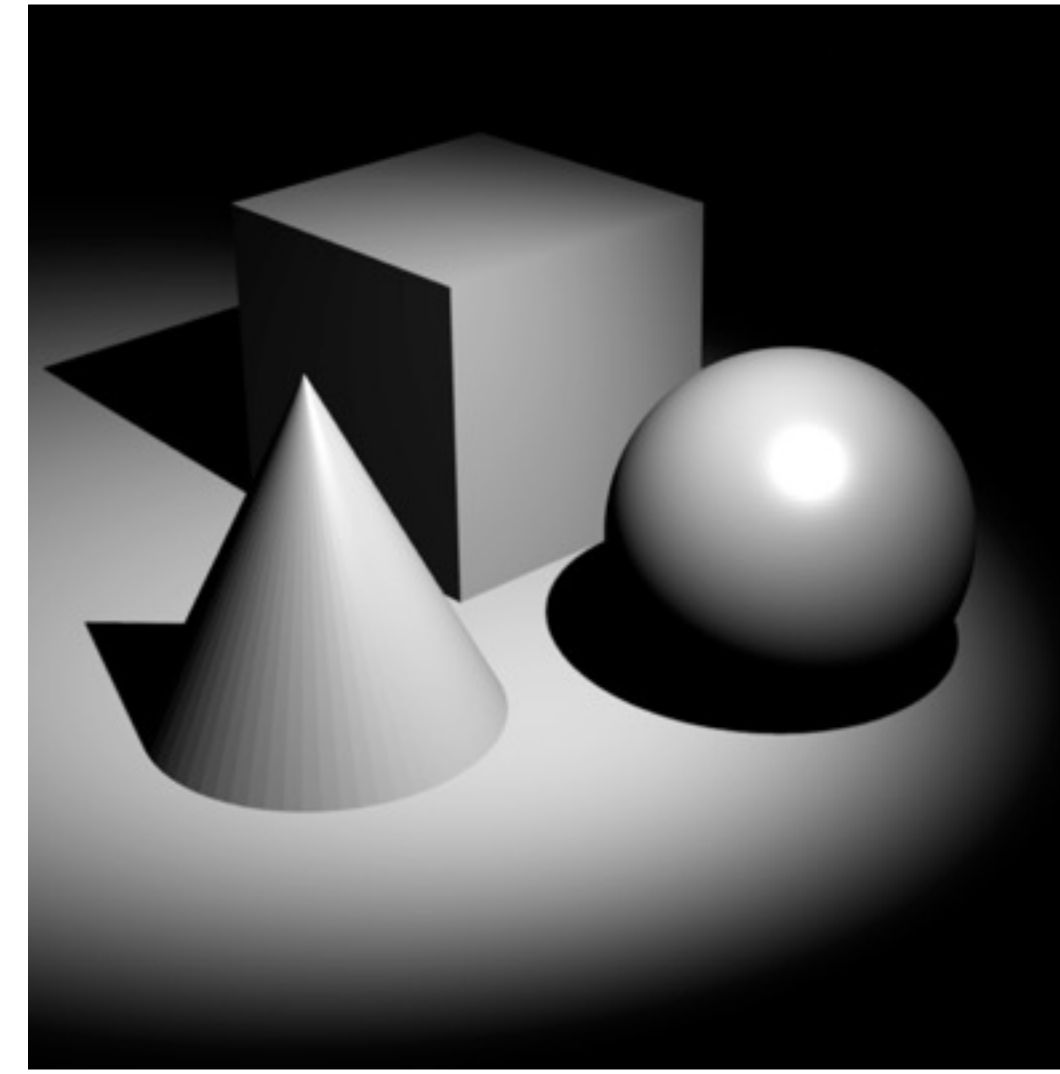
- have just a position in space
- emit light equally in all directions
- Intensity falloff with distance d is:
  $I = I_0 / (ad^2 + bd)$
  – this means that the falloff is less harsh than in nature. Why??

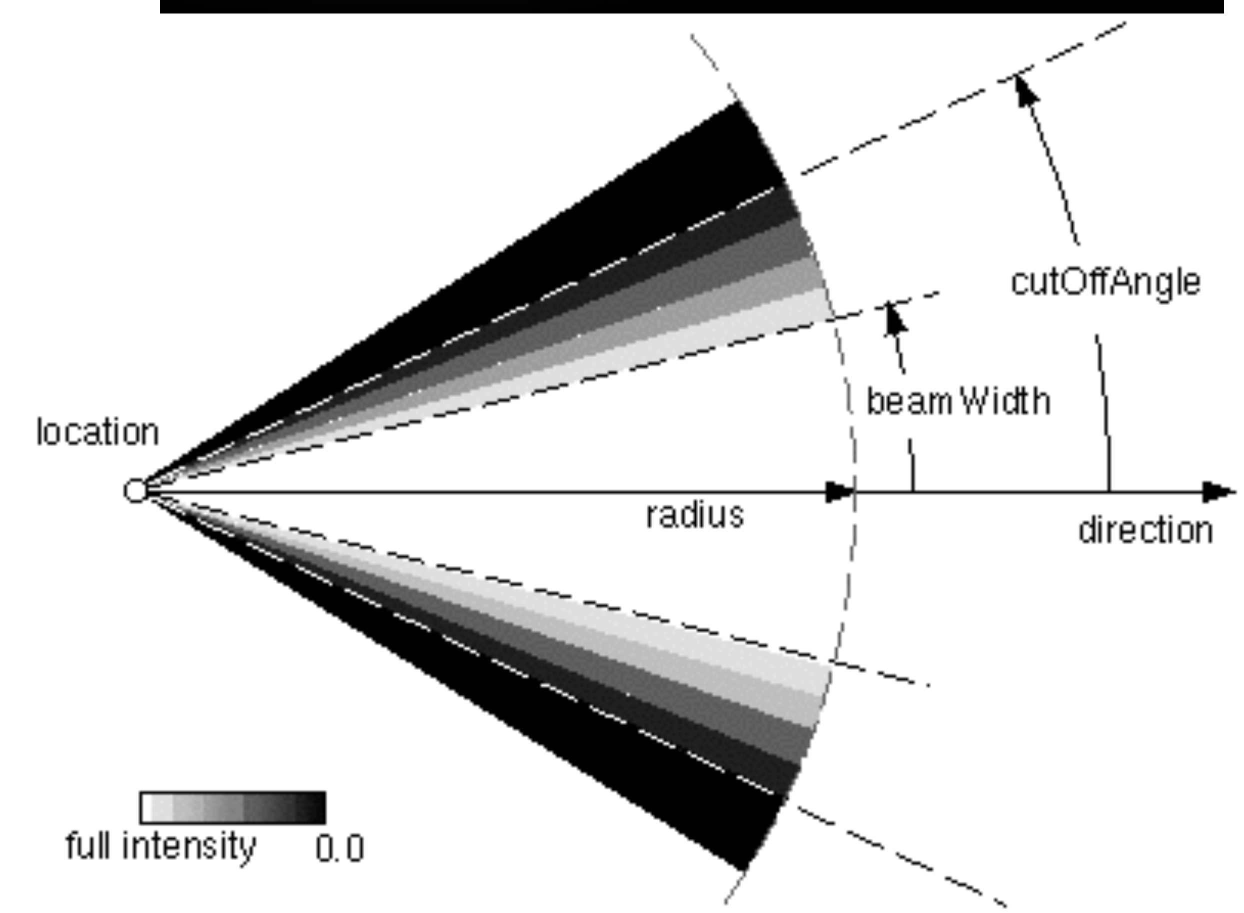
- Light source itself is invisible in the image
  – since points are infinitely small

- Shadows have sharp edges
- Shadows get bigger with distance from object

Spot Lights

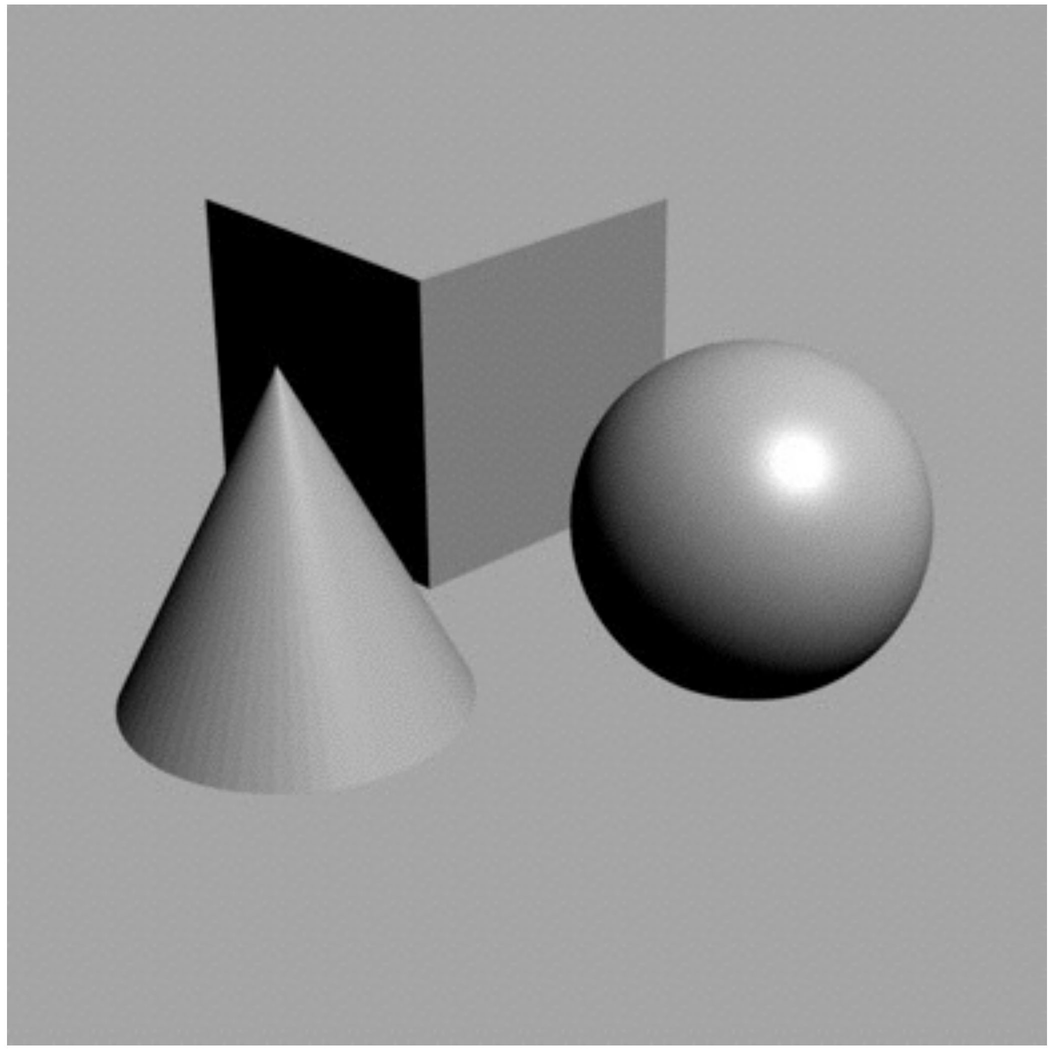
- have a position and orientation in space
- have an opening angle and a parameter controlling the softness of the beam's borders
- Intensity falloff with distance d is:
  $I = I_0 / (ad^2 + bd)$
  - this means that the falloff is less harsh than in nature. Why??
- Intensity falloff with angle depends on exact model
- light source itself invisible
- object shadows have sharp edges
- transition to surrounding shadow is soft.





http://www.web3d.org/x3d/specifications/vrml/ISO-IEC-14772-VRML97/Images/spotlight.gif

Distant Light Source (a.k.a. the sun)



- size of the earth (radius) = 6.370 Km
- distance from earth to sun = 150.000.000 Km
- distance to the sun is practically equal for all points on earth
  - hence light falloff with distance is not noticeable for sunlight

- distant light source in 3DCG has only a direction and a fixed intensity
- good and neutral first step for lighting a scene!
- shadows should have sharp edges

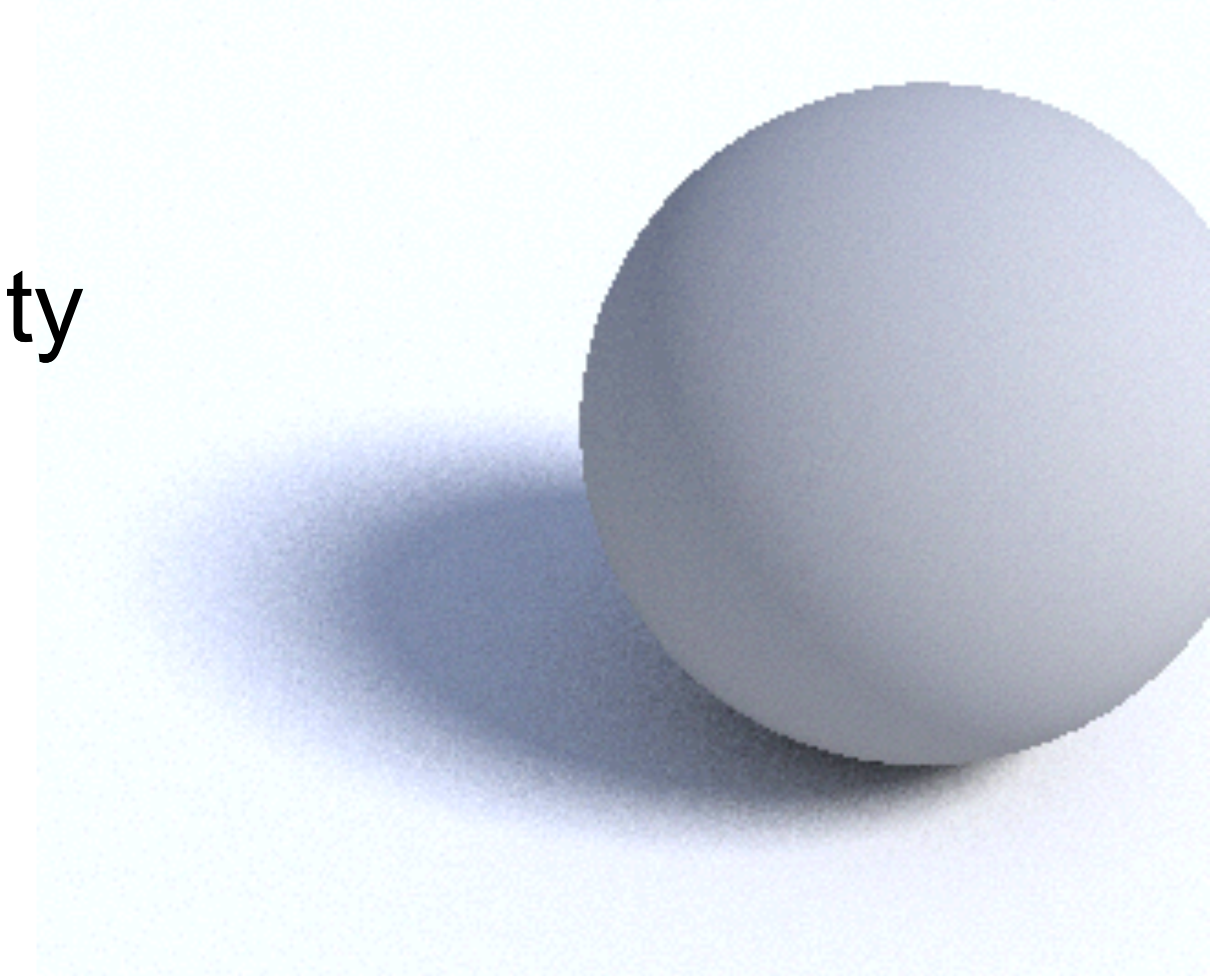
Ambient Light

- Equivalent in nature:
  - light emitted from the entire sky
  - indirect light reflected from objects in the scene
- intensity is equal from all directions
- creates low contrast images by itself

http://de.wikibooks.org/wiki/Datei:Blender3D_li_ambiant_light_occl.jpg

- ambient light is a good way to light up harsh shadows
- combination with one distant light can already create a decent daylight simulation (sun + sky)

Area Light Sources



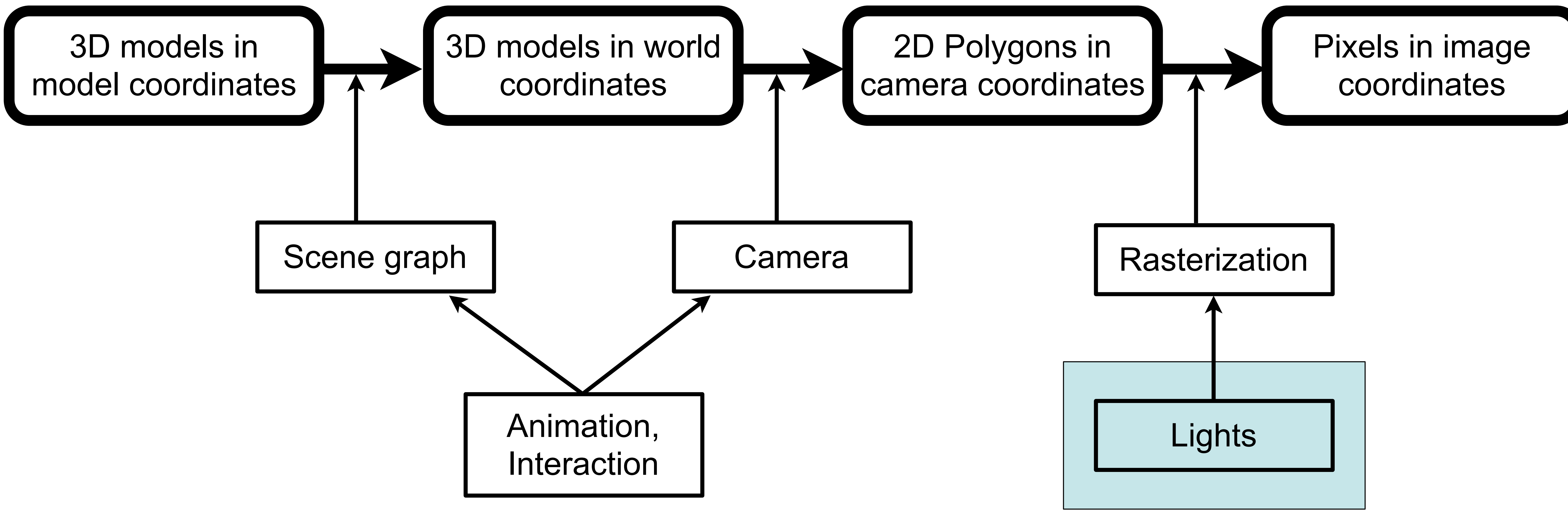
http://upload.wikimedia.org/wikipedia/commons/4/46/Area_light_source_soft_shadow.png

- described by object geometry and light intensity
- entire area emits light
- all natural light sources are of this kind
  - even a light bulb has a surface > 0

- shadows have soft edges
- light falloff with distance

- computationally difficult, take very long to render correctly
- can be simulated by many point light sources
- need global illumination techniques for correct rendering (see later)

The 3D Rendering Pipeline (our version for this class)



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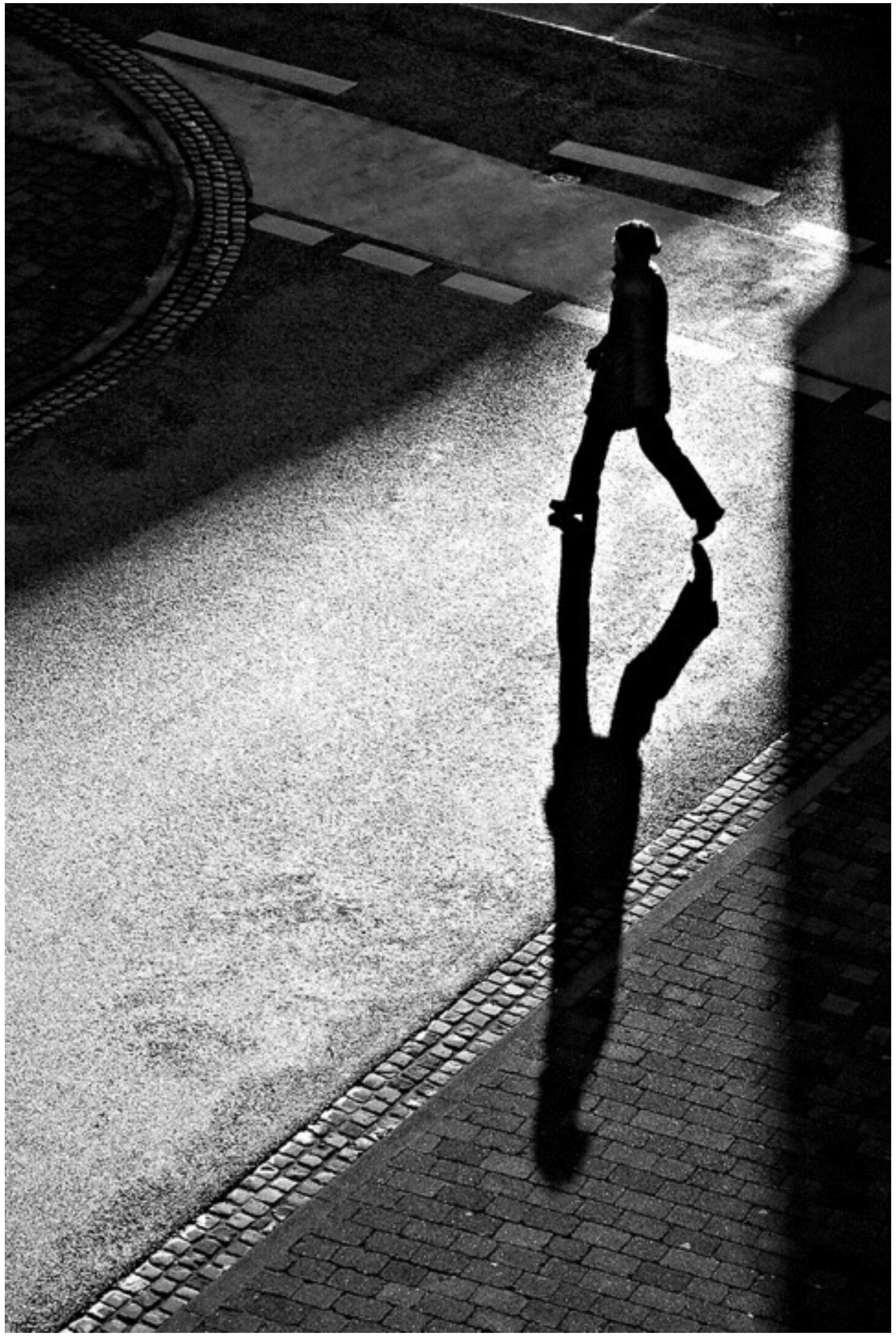
Shadows in Nature

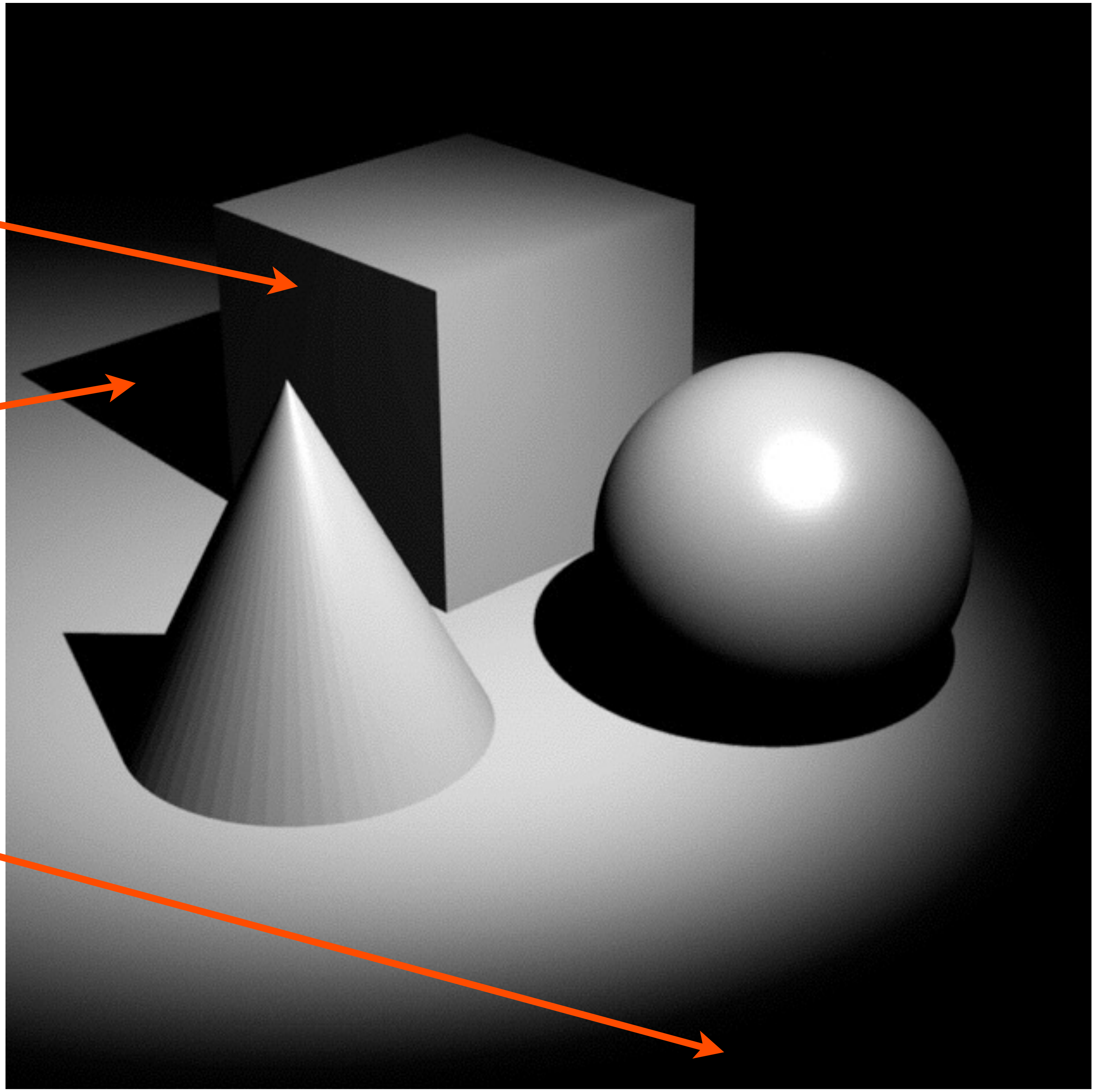
- Very important for spatial vision
- Artistically used in all art forms
  - drawing, painting
  - photography
  - cinematography
- Practically never really black
- Types of shadows in this image?



http://www.heise.de/imagine/Vzl2PeXewMuSsFADy2UvZXFzFUk/gallery/shadow-lines.jpg

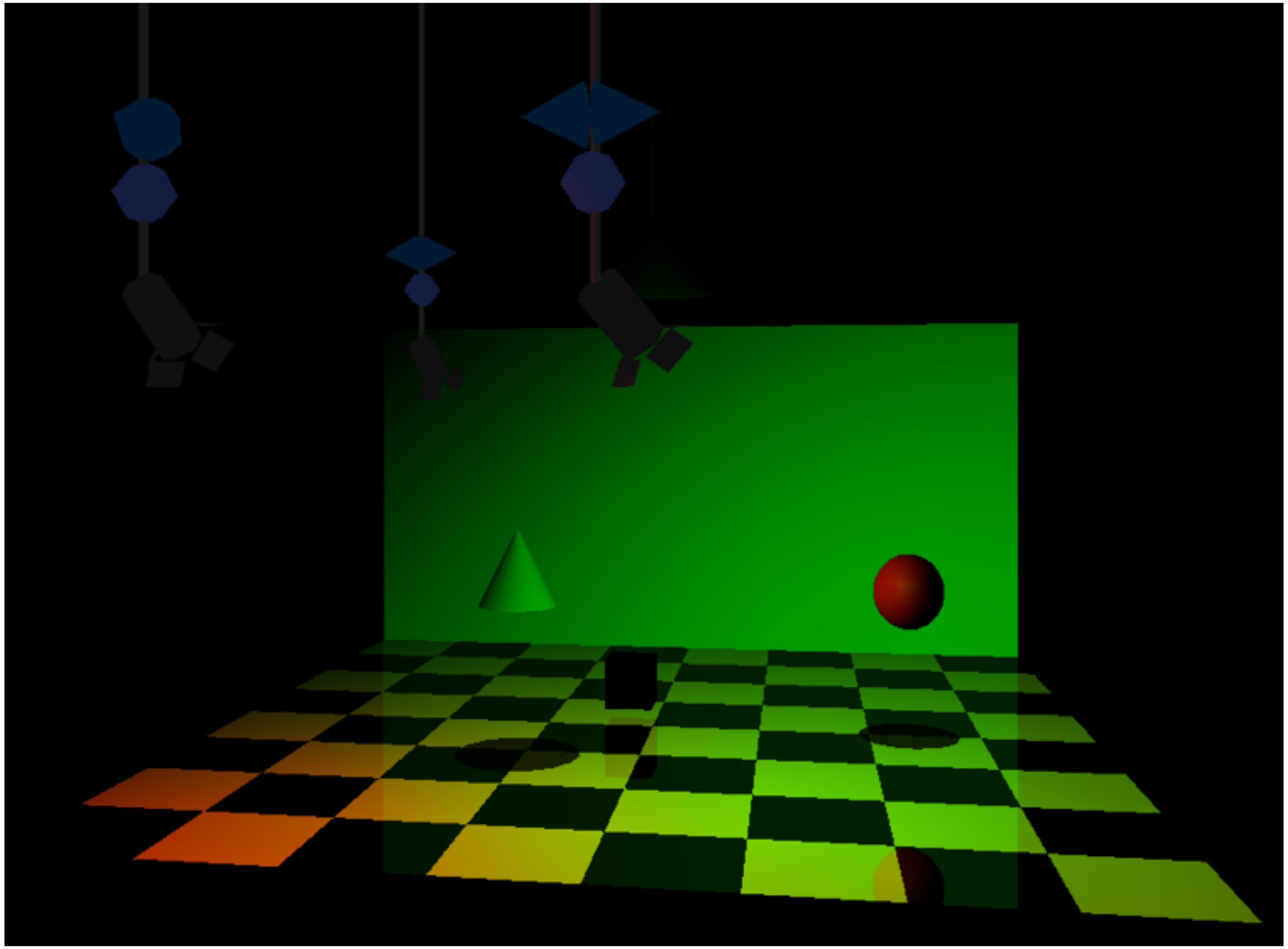
Types of Shadow

- Object shadow
  - the shadow side of objects
  - exists in free space
- Cast shadow / drop shadow
  - the shadow cast onto another object (or the ground)
  - need another object or ground plane
- Shadow as the absence of light
  - no light source reaches this place



Cheating a Shadow (and a Reflection!)

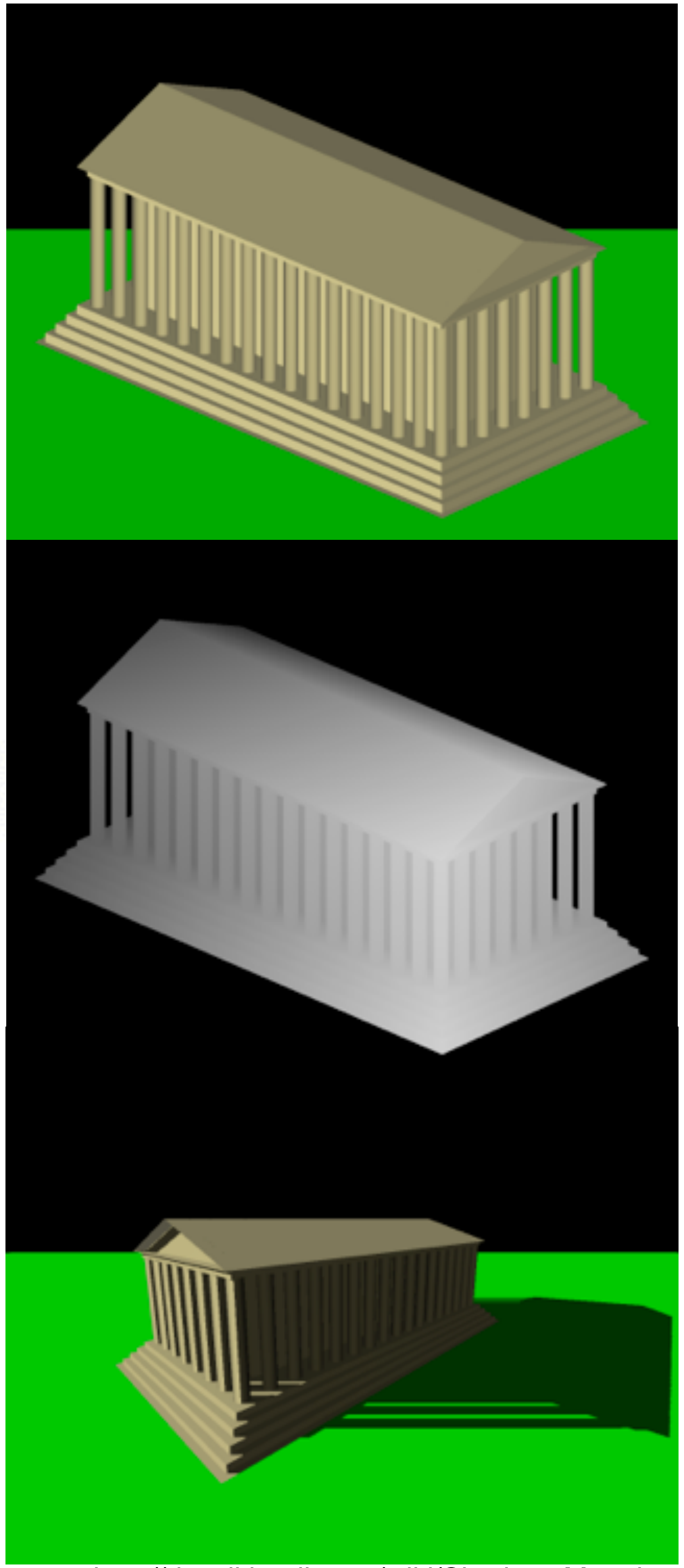
- Try to guess how this simple VRML world creates shadows and reflections in real time!



Shadow Maps

- From the position of a light source, record a depth buffer
  - for each pixel in buffer, we know how far from the light it is
- For each rendered pixel in the camera image, check distance of its surface point to the light
  - if closer than shadow buffer: in this light
  - If further away: in the shadow of this light
- If scene or lights change, shadow map must be recalculated

http://ecx.images-amazon.com/images/I/41YwkCd19DL._SL500_AA300_.jpg



http://de.wikipedia.org/wiki/Shadow_Mapping

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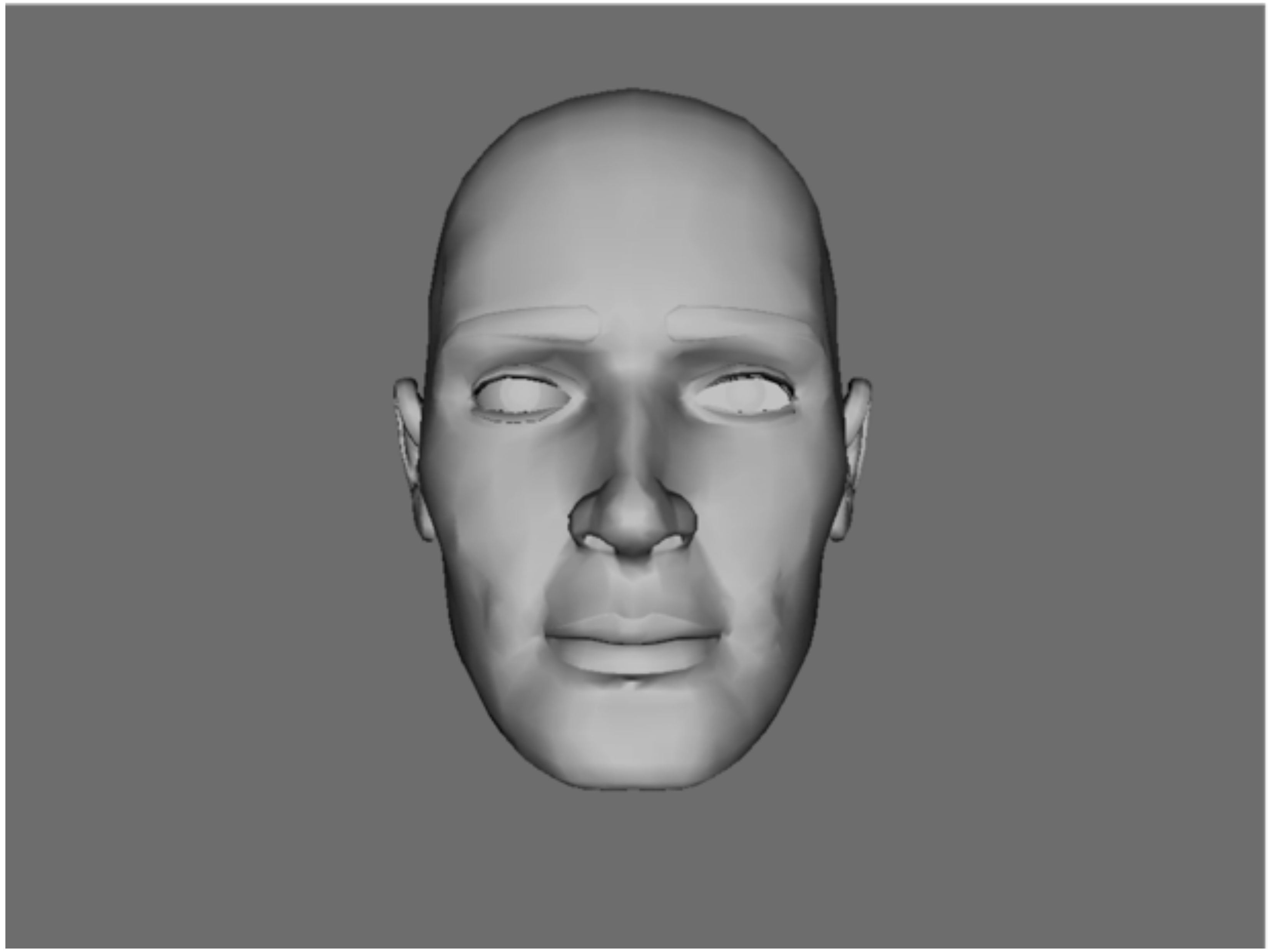
Using Lights

- A few recipes to get started with lighting
- Really good lighting design is an art in itself
  - 3D animated movies hire full time light designers

Headlight

- Default light setup in VRML
- Light source in camera position
- Scene can be viewed from arbitrary directions
- Creates no visible drop shadows
  - why? or does it?

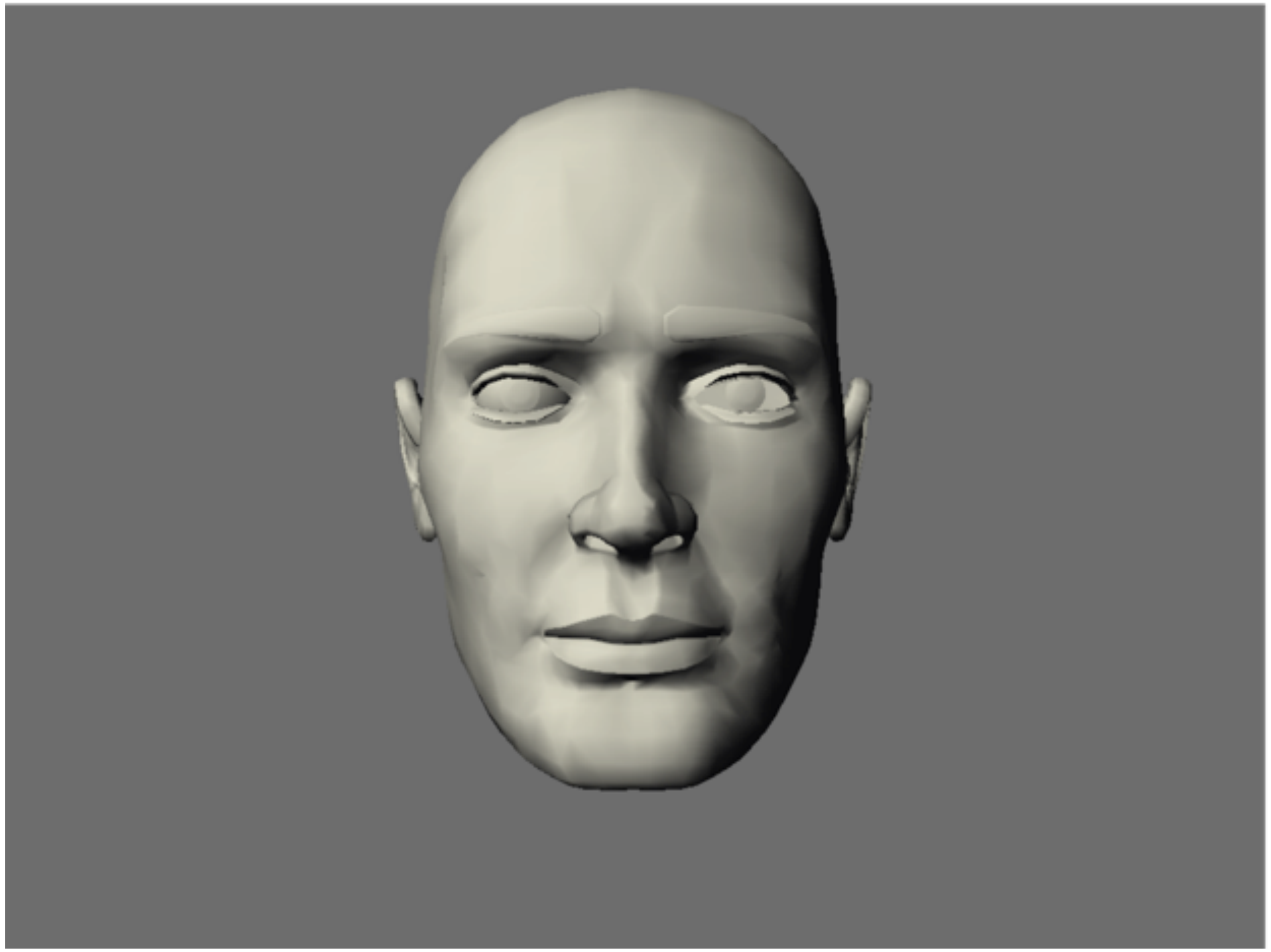
- Creates rather „flat“ images
- Unnatural „flashlight“ look
- Good in combination with other setups for lighting up the scene



http://www.online-superpreis.de/images/produkte/476-stirnlampearcas9er400.jpg

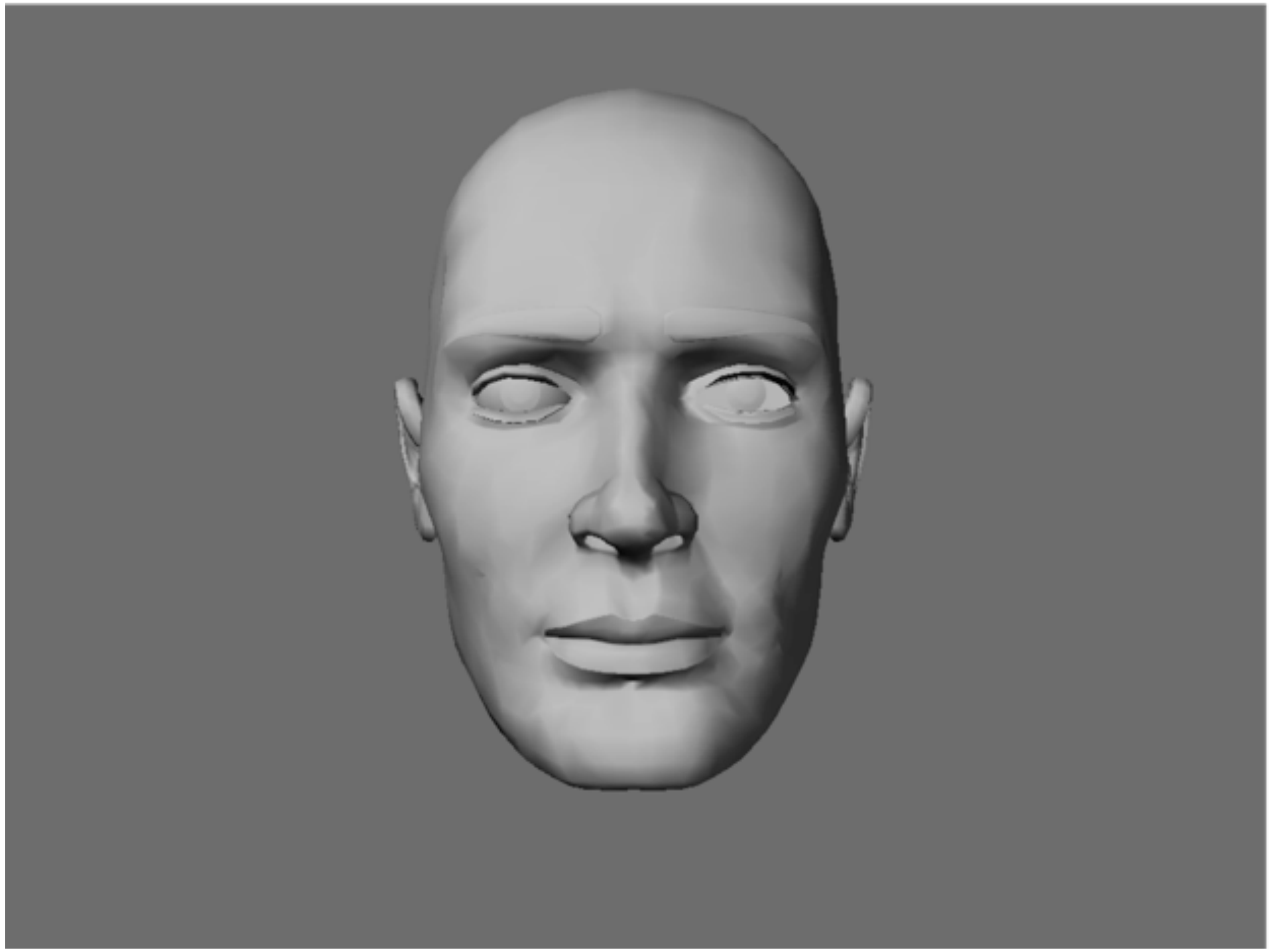
Daylight Simulation

- Sun
  - distant light source
  - warm color tint
- Sky
  - ambient light
  - cool color tint
  - can be simulated by directional light from opposite side



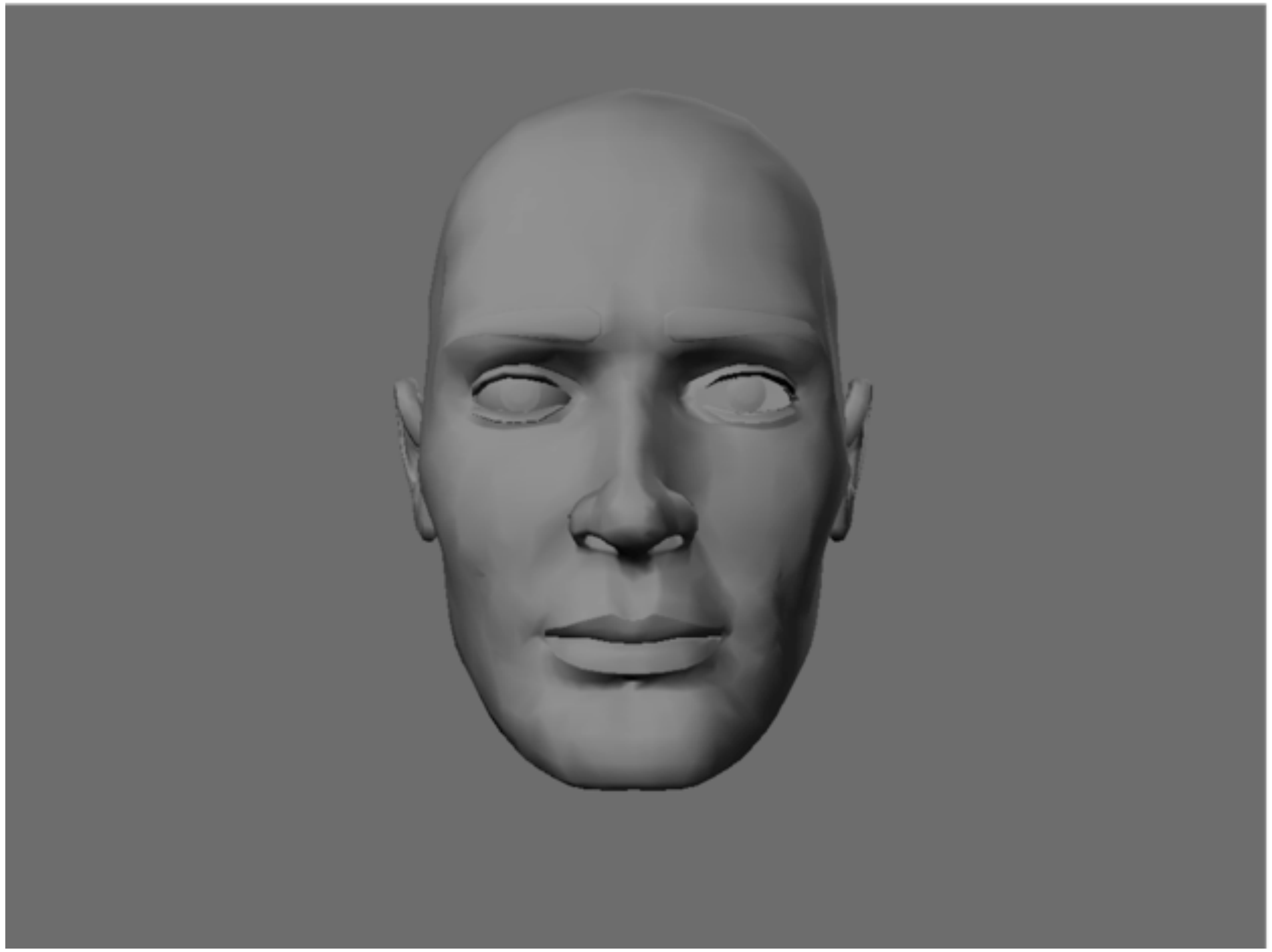
- creates a natural look
- can simulate daytimes (how??)
- can simulate sunny/cloudy weather (how??)

Simple Portrait Light Setup



- Borrows ideas from daylight
  - 1 main light source
  - direction: traditionally from top left
  - creates overall basic brightness
- One or several brighteners
  - from opposite sides
  - to light up shadows
  - sum of their brightness less than half of main light (why?)
- Basic setup for scenes viewed from just 1 direction

Sided Light



- Effect light known from movies
  - use only in addition to others
- Enhances object contours
- Placement behind the subject
  - not straight behind, but off-axis
  - positioning is difficult in real world
  - easier in graphics, but still:
  - highly position-dependent

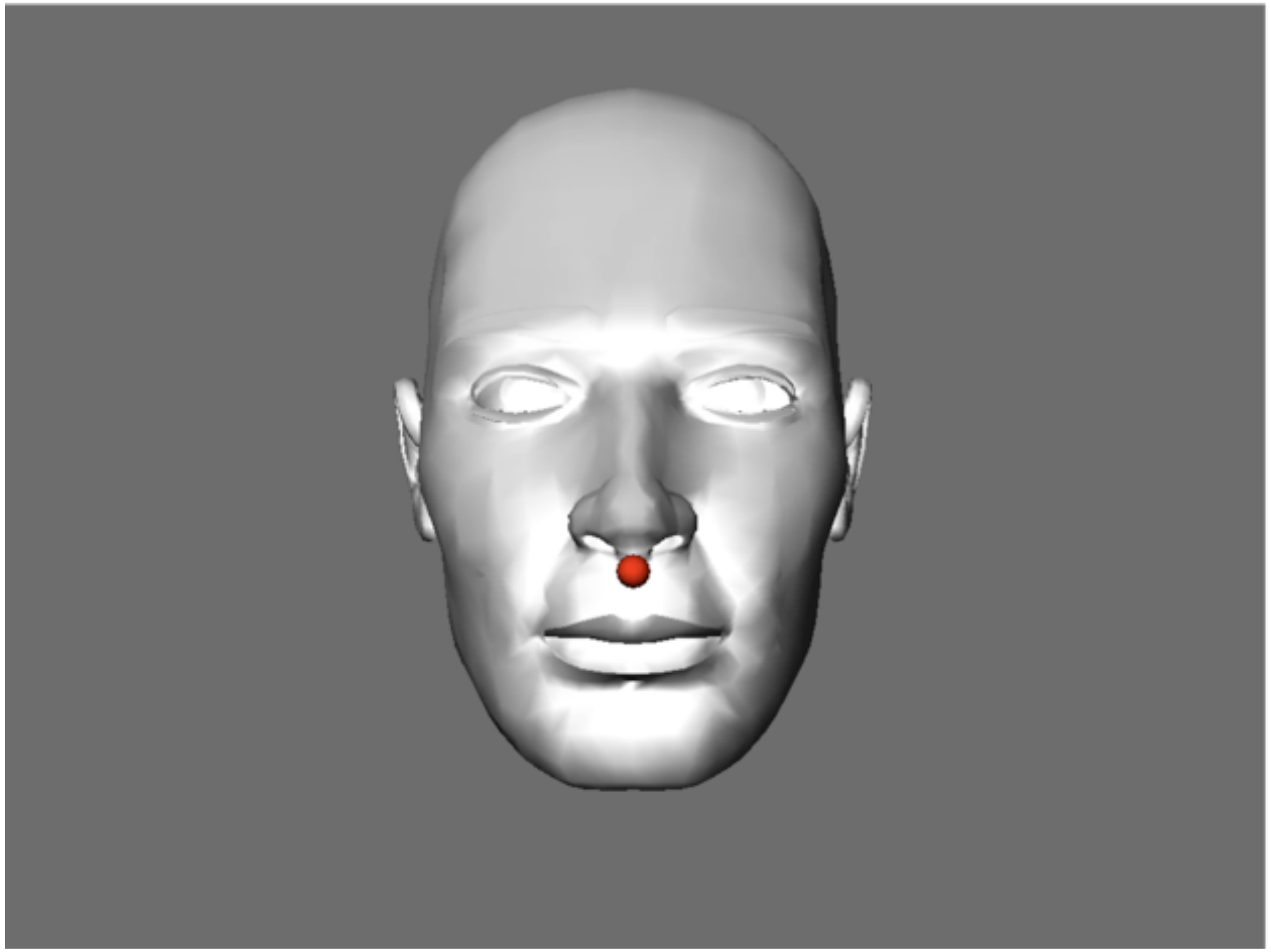
- Can be used to clearly separate an object from the background.
- will highlight its silhouette.

Cheating with Light

- Light sources in computer graphics are invisible
  - only their effects on objects are visible!

- Can be positioned anywhere in a scene to light up dark areas

- Example on this slide is exaggerated!



Dramatic Lighting

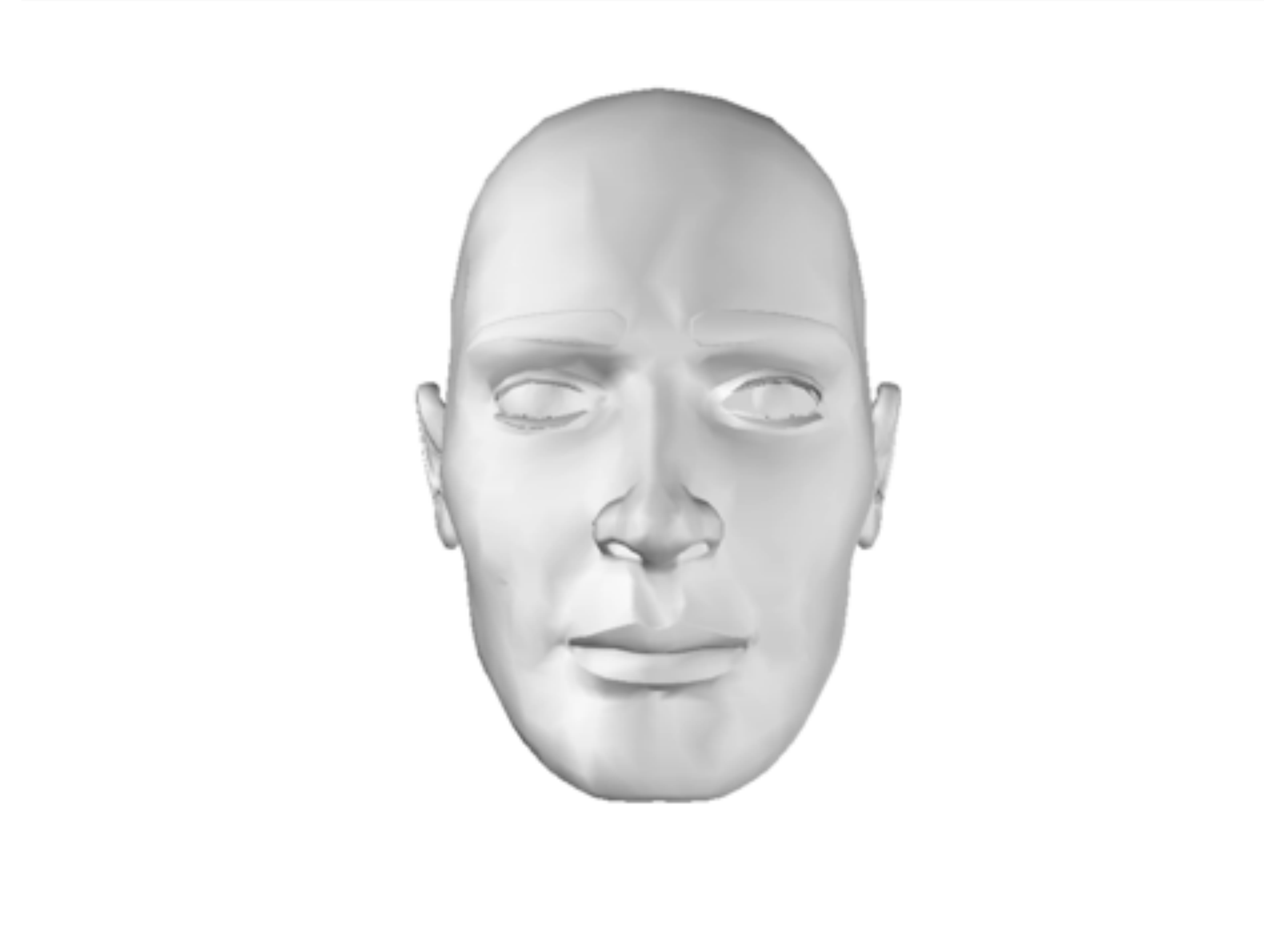
- Combination of unnatural lights
  - coming from below
  - strong colors
  - mostly low key

- Unlit shadows can create mystery

- Can be supported by unnatural camera
  - from below
  - wide angle and close up

High Key, Low Key

- High Key: all colors in image are bright
  - start with very even lighting
  - frontal light will remove shadows
  - danger of saturated white
  - communicates light and cleanliness



- Low Key: all colors are very dark
  - often uses sided light
  - objects can be reduced to their contours
  - communicates e.g., mystery

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Surfaces in Nature

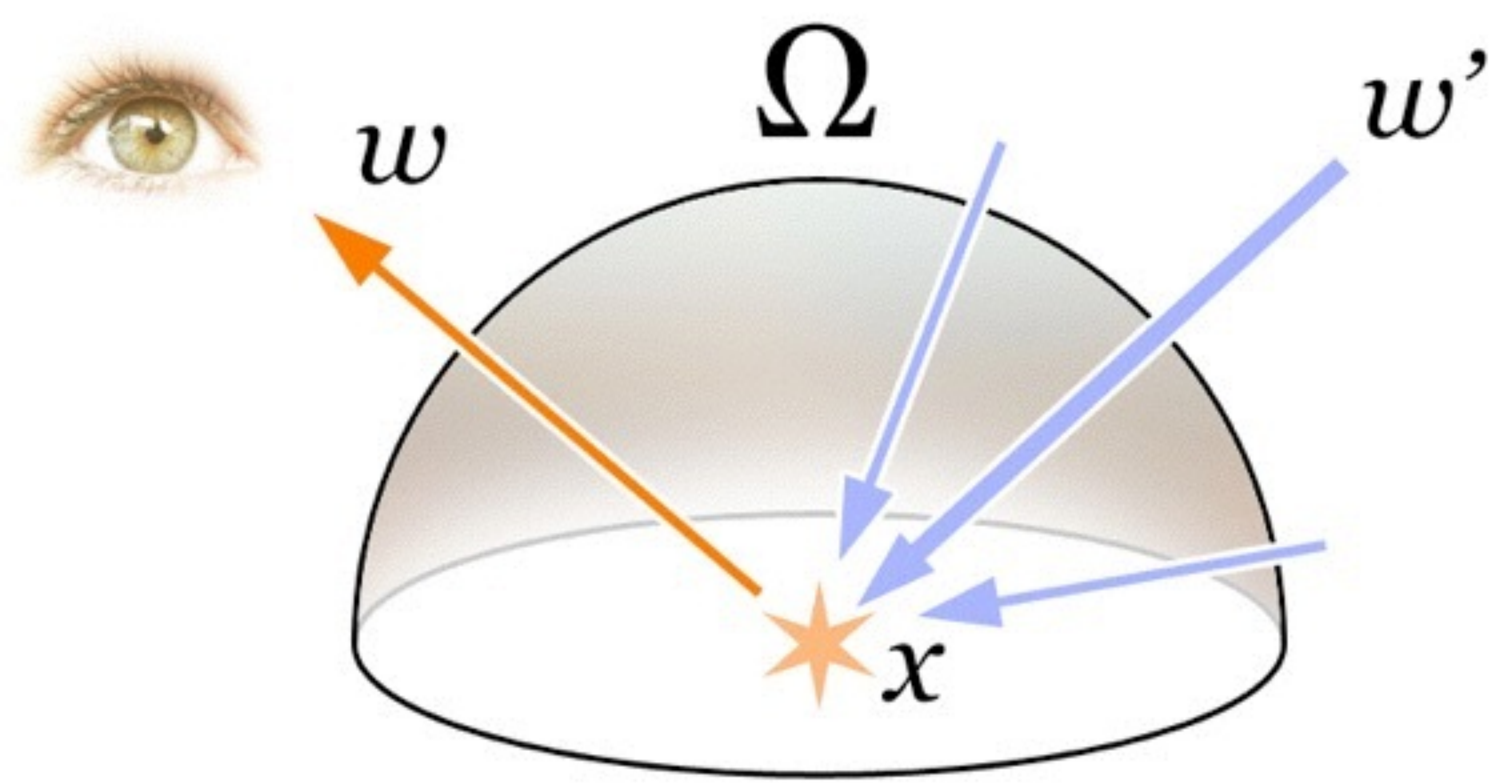
- What does a surface do to light? (mini-Brainstorming)

-
  -
  -
-
  -
  -
-
  -
  -

The Rendering Equation [Kajiya '86]

$$\underline{I_o(x,\vec{\omega})} = \underline{I_e(x,\vec{\omega})} + \int_\Omega \underline{f_r(x,\vec{\omega}',\vec{\omega})}\,\underline{I_i(x,\vec{\omega}')}\,\underline{(\vec{\omega}'\cdot\vec{n})}\,d\vec{\omega}'$$

- I_o = outgoing light
- I_e = emitted light
- Reflectance Function
- I_i = incoming light
- angle of incoming light

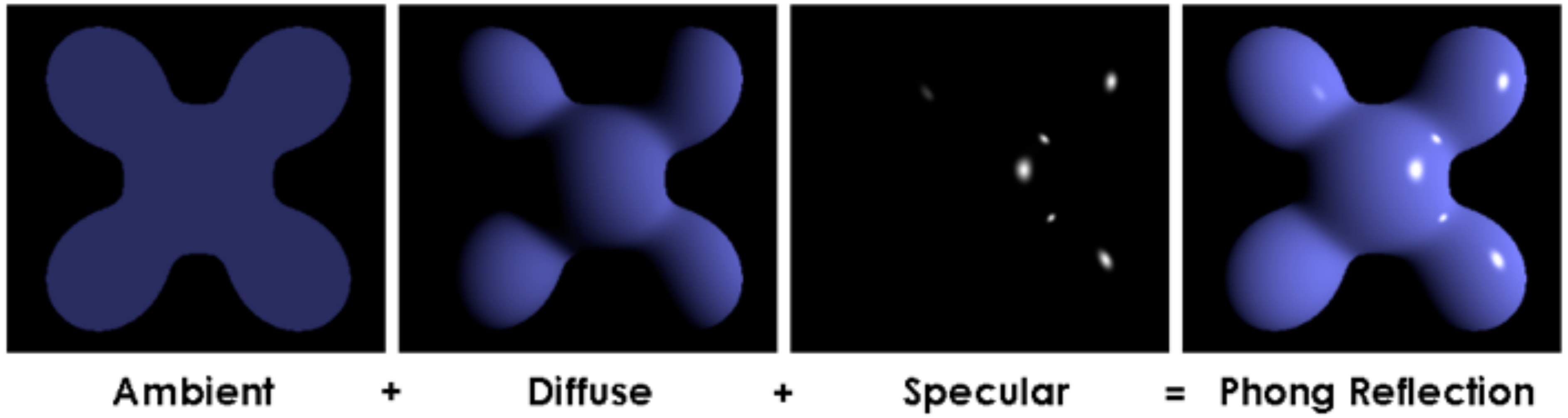


http://en.wikipedia.org/wiki/File:Rendering_eq.png

- Describes all flow of light in a scene in an abstract way
- doesn't describe some effects of light:
  -
  -

Phong's Illumination Model [Bùi Tường Phong, 1973, PhD thesis]

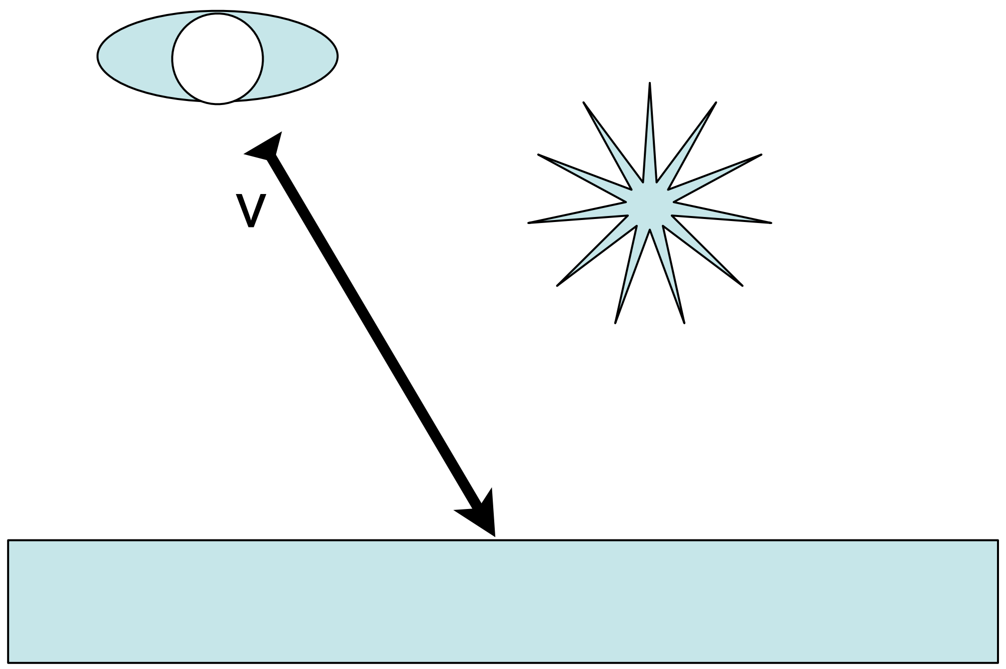
$$I_o = I_{amb} + I_{diff} + I_{spec}$$



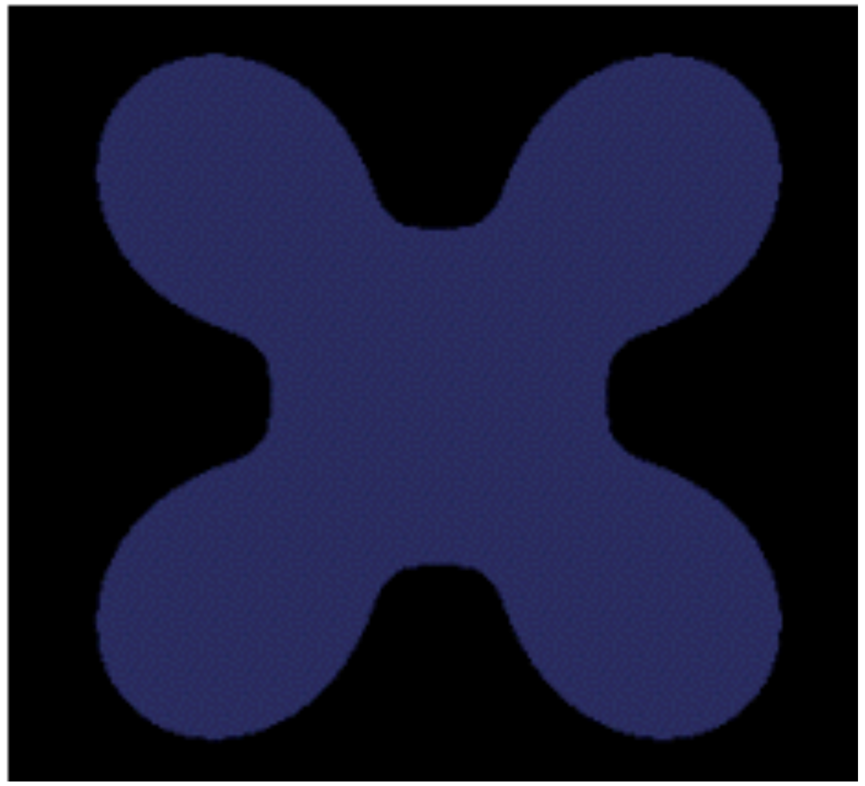
- strong simplification and specialization of the situation
  - just 1 light source from a clear direction l
  - viewing direction is given as v
- only 3 components:
  - ambient component: reflection of ambient light source from and in all directions
  - diffuse component: diffuse reflection of the given light source in all directions
  - specular component: „glossy" reflection creating specular highlights

Ambient Component

- I_a = Intensity of the ambient light source
- independent of any directions
- can simulate a „glowing in the dark“
- can be seen as the equivalent to emitted light I_e in the rendering equation

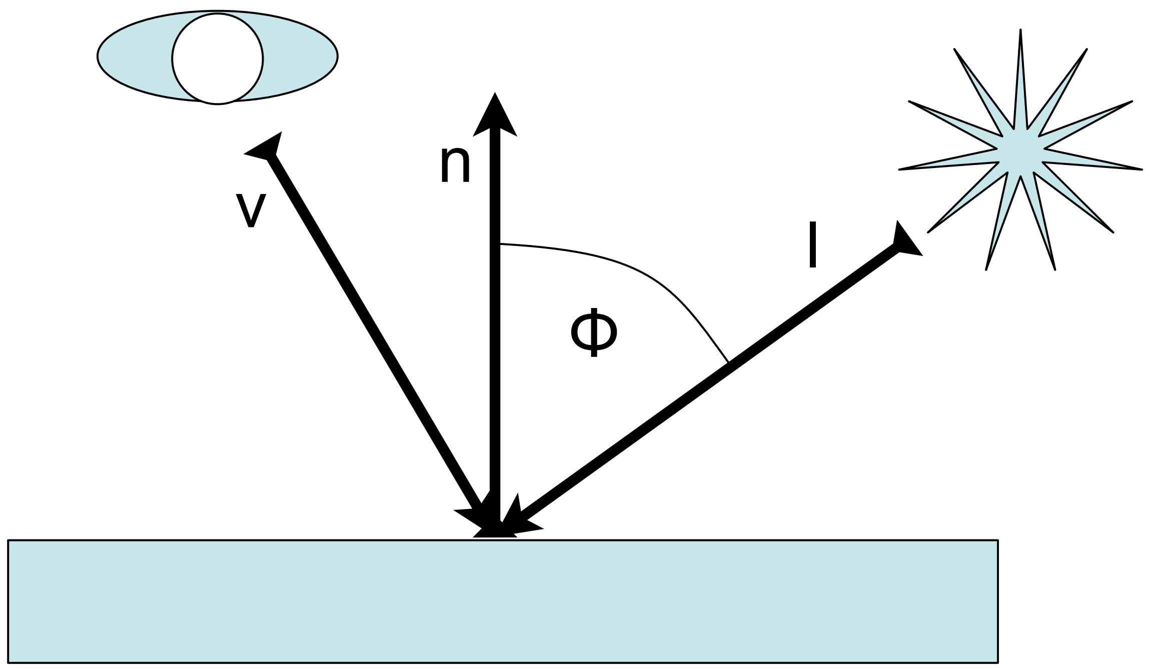


$$I_{amb} = I_a k_a$$



Diffuse Component

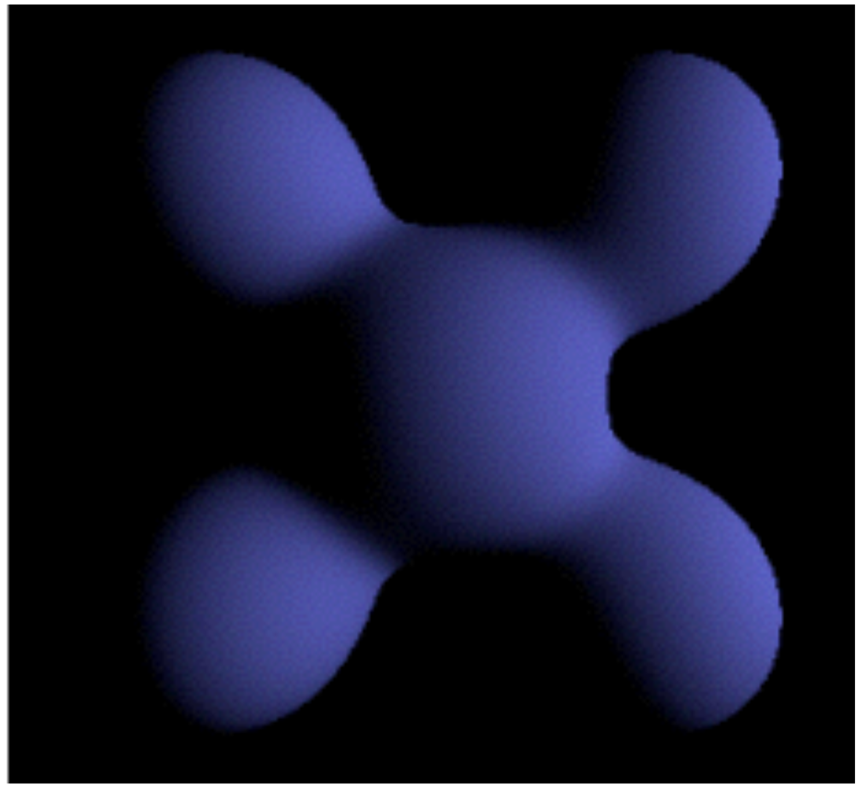
- diffuse reflection is equal in all directions
- depends on the angle of incident light
  - light along the surface normal : maximum
  - light perpendicular to the normal: 0



- cosine function describes the energy by which a given area is lit, dep. on angle
  - hence, cosine is used here

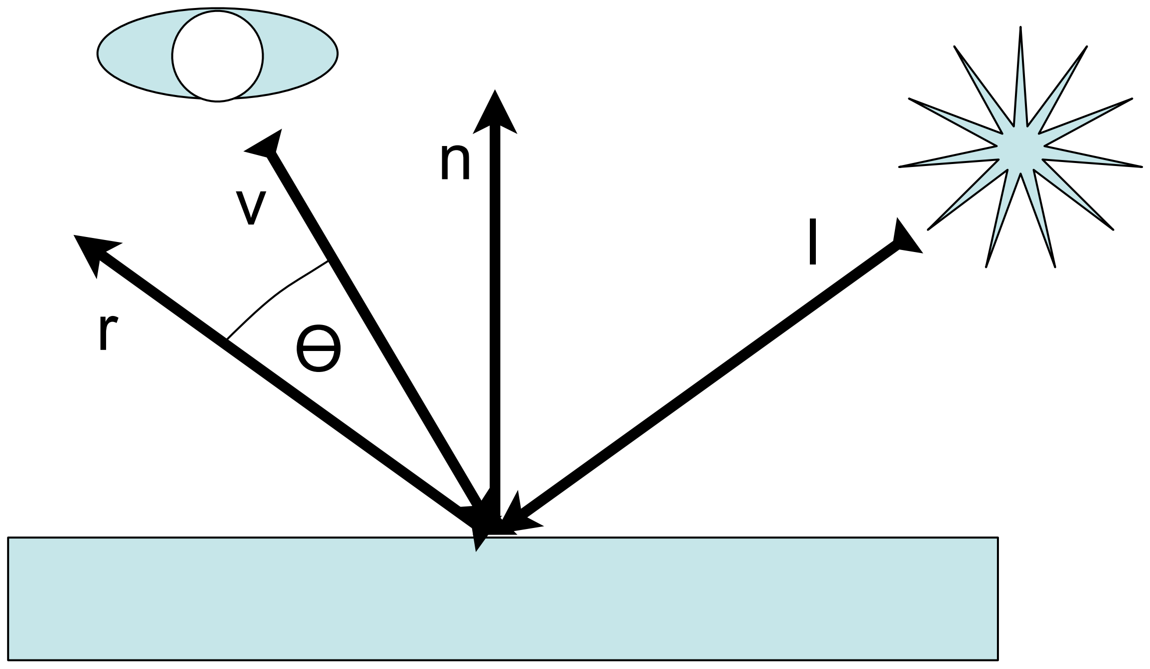
$$I_{diff} = I_i k_d cos\phi = I_i k_d(\vec{l} \cdot \vec{n})$$

- „Lambertian" surface
- visual equivalent in nature: paper

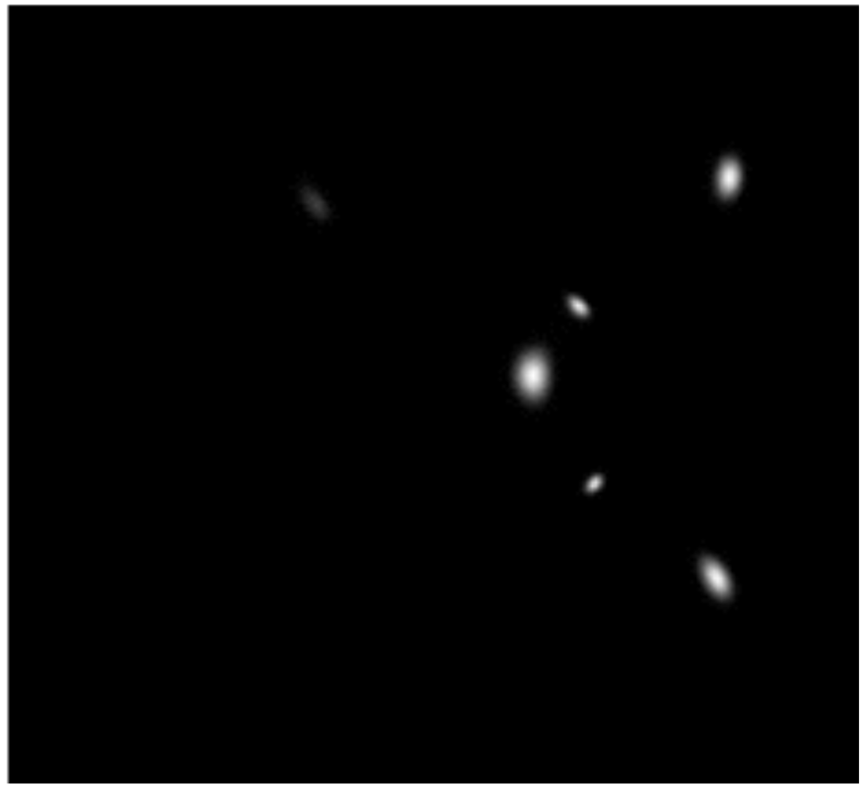


Specular Reflection

- let r be the reflection of l on the surface
- specular reflection depends on the angle between v and r
- v = -r: maximum
- v and r perpendicular: minimum
- function $\cos^n$ behaves correctly
  - exponent n determines how wide the resulting specular highlight is
  - other functions could be used as well

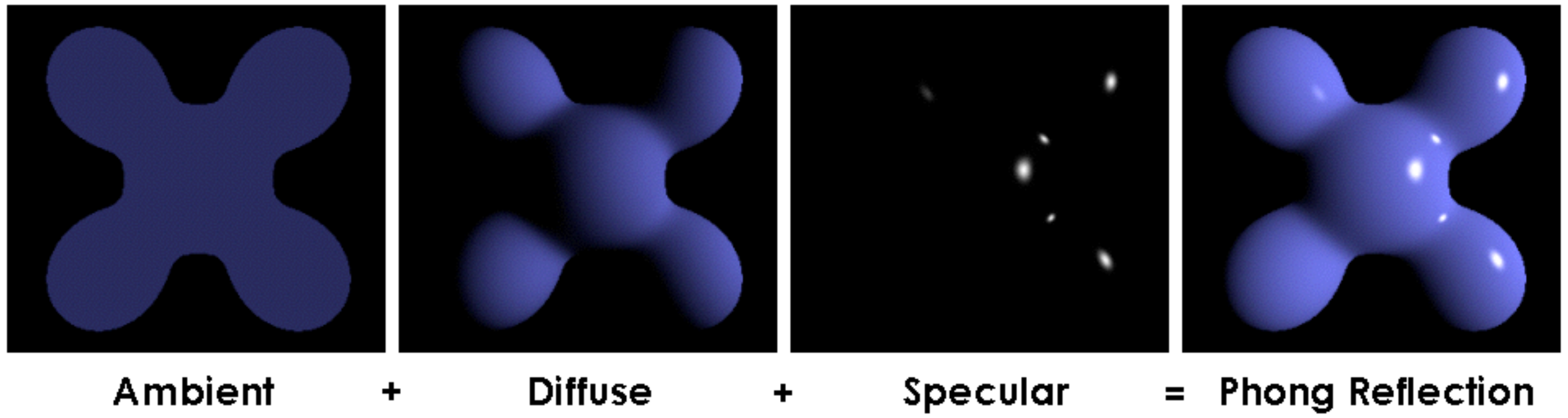


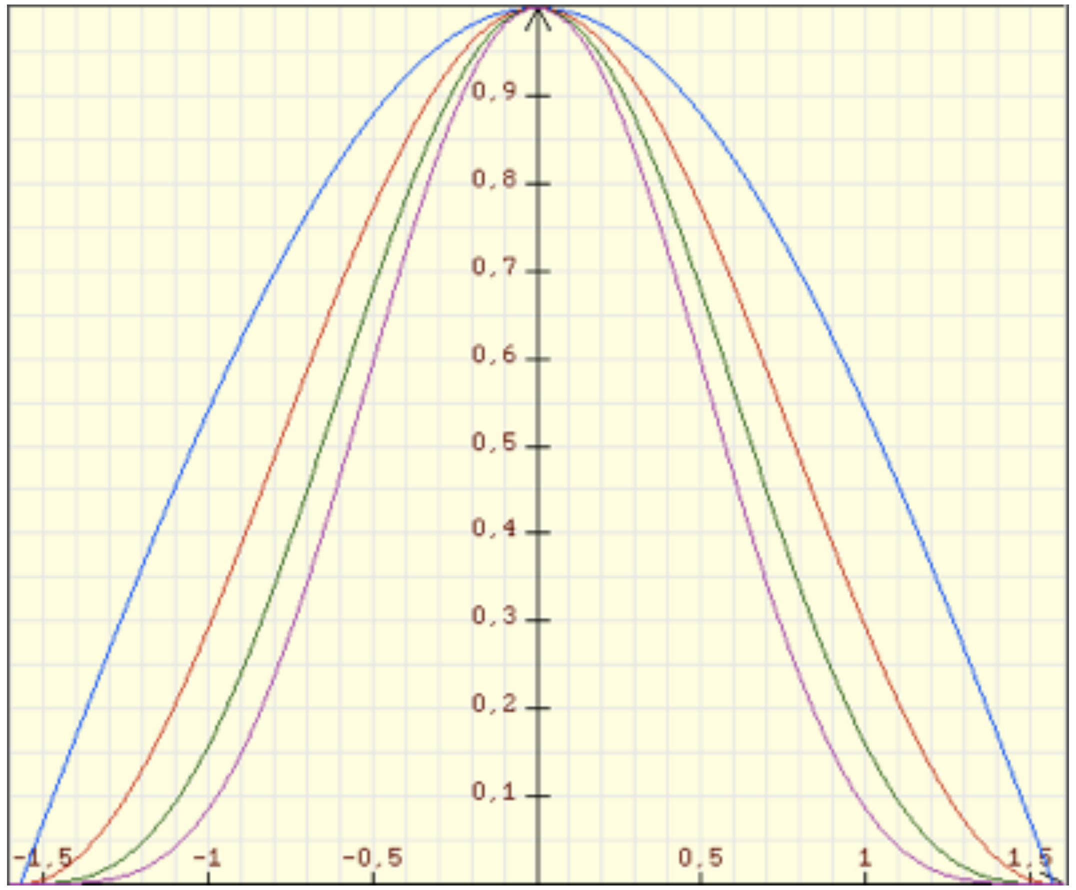
$$I_{spec} = I_i k_s cos^n\theta = I_i k_s(\vec{r}\cdot\vec{v})^n$$



Tweaking the Parameters

$$I_o = I_{amb} + I_{diff} + I_{spec} = I_a k_a + I_i k_d(\vec{l} \cdot \vec{n}) + I_i k_s(\vec{r} \cdot \vec{v})^n$$





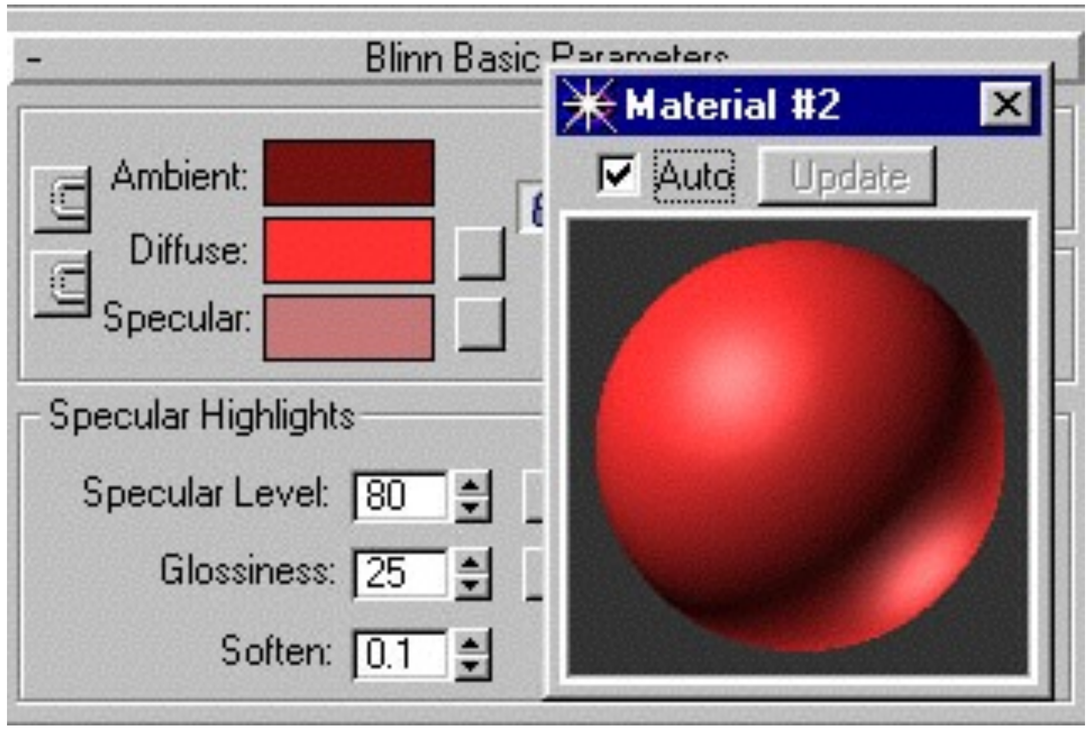
- choose k_s = 0 for perfectly matte material
- choose k_a > 0 to avoid harsh shadows
- keep k_a small to avoid „glowing“ objects
- add in some k_s > 0 to add gloss
- adjust the size of specular highlights with n

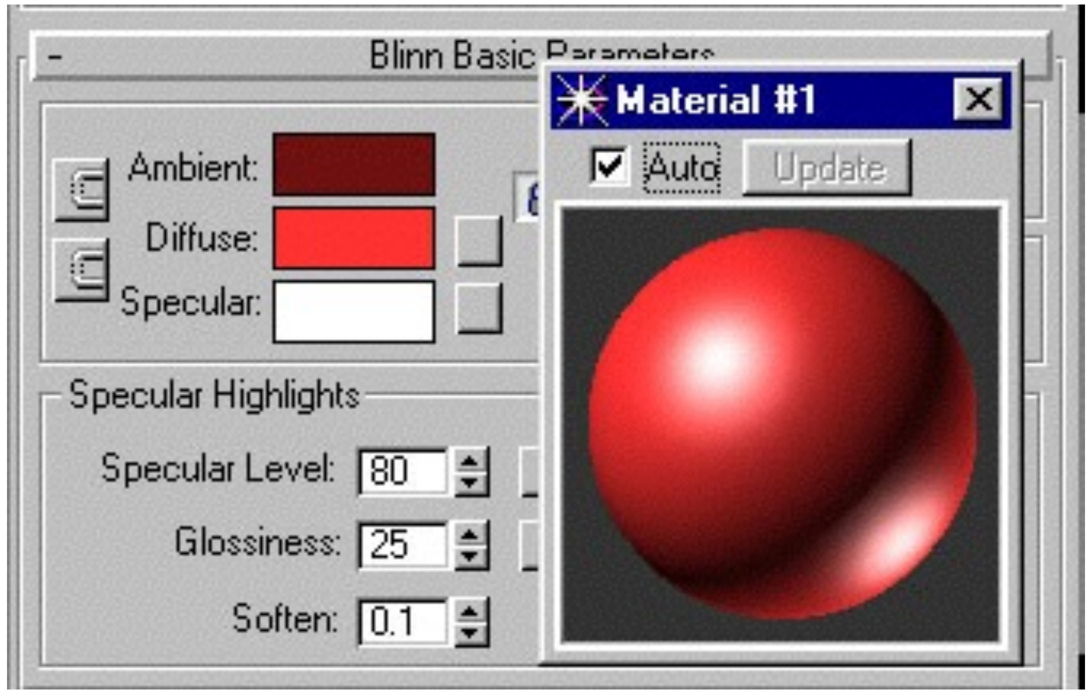
- all of these calculations generalize to (RGB) color, of course!

The VRML Material Node

```
Material {
  exposedField SFFloat  ambientIntensity  0.2            # [0,1]
  exposedField SFColor  diffuseColor      0.8 0.8 0.8    # [0,1]
  exposedField SFColor  emissiveColor     0 0 0          # [0,1]
  exposedField SFFloat  shininess         0.2            # [0,1]
  exposedField SFColor  specularColor     0 0 0          # [0,1]
  exposedField SFFloat  transparency      0              # [0,1]
}
```

shininess in VRML is multiplied by 128 to produce n in the lighting model.





http://dxyner2000.com/tutorials/tut3.1.htm

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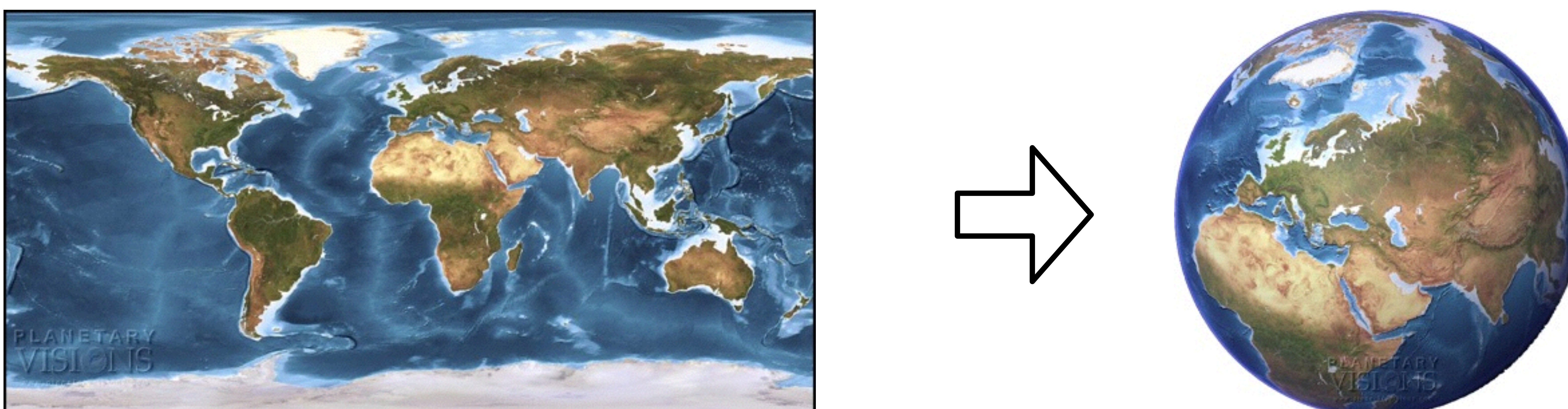
http://www.planetaryvisions.com/Texture_map.php?pid=4128

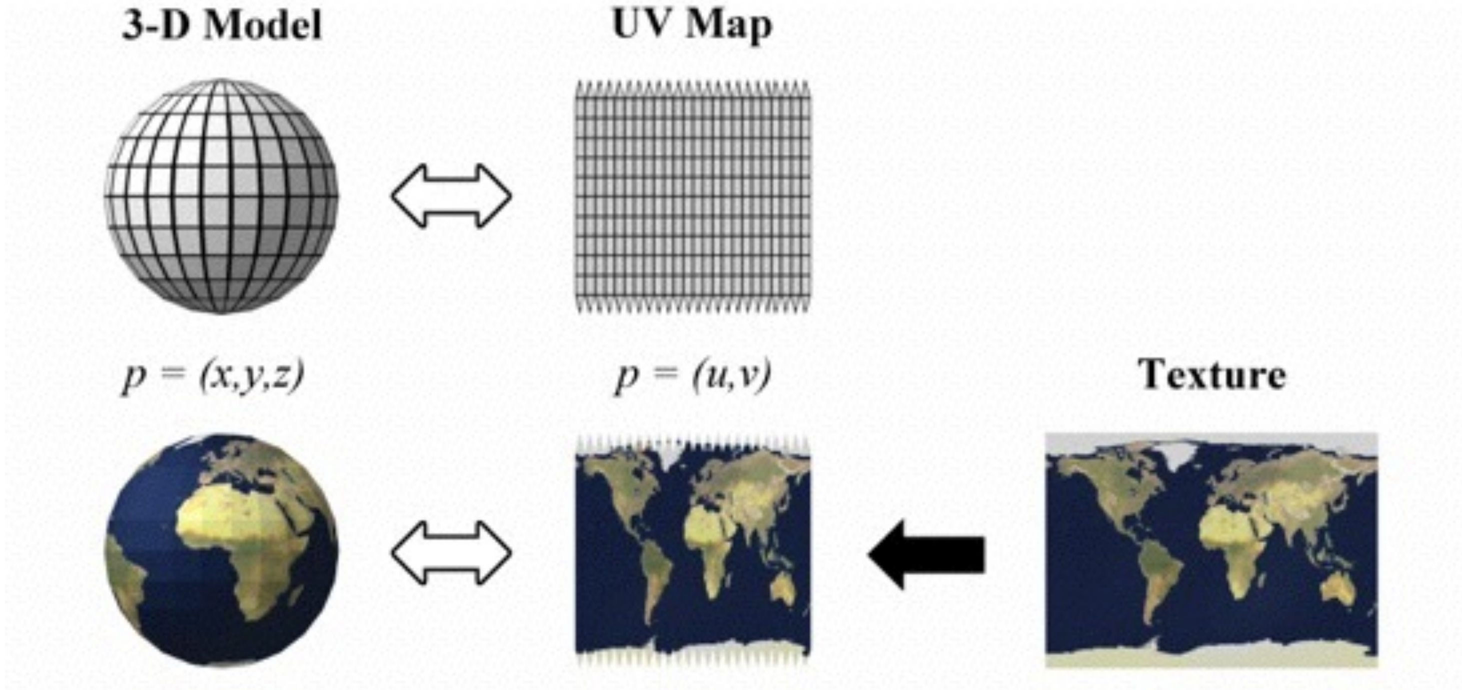
Textures and Maps

- one of the simplest and oldest ways to achieve good looking objects with simple geometry
- texture design is a very complex task, needs a lot of imagination!
- idea: use a bitmap image, shrink wrap around the object
- use bitmap contents for object surface color: image map
  - can be used for other parameters, e.g., normal, elevation, transparency, reflection
- problem: what does shrink wrap mean exactly?

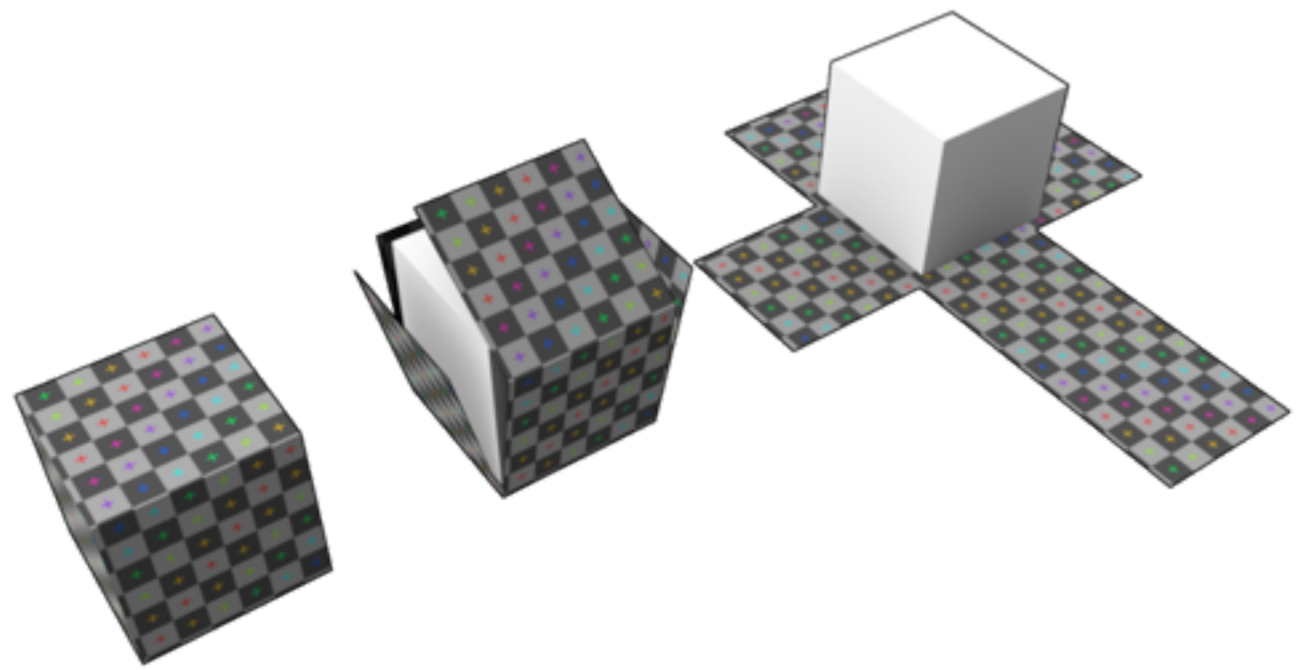


Texture Coordinates and UV Mapping

- each texture is mapped to a 1x1 square
- each object defines u,v coordinates
  - such that u,v are both between 0 and 1
- straightforward for geometric primitives
  - different possibilities
  - conventions exist
- not so easy for polygon models
  - can be defined per vertex
  - ...but who wants to do this?
  - simplifications: shrink a sphere onto the object
    - works fine with convex objects
    - always tricky for complicated objects



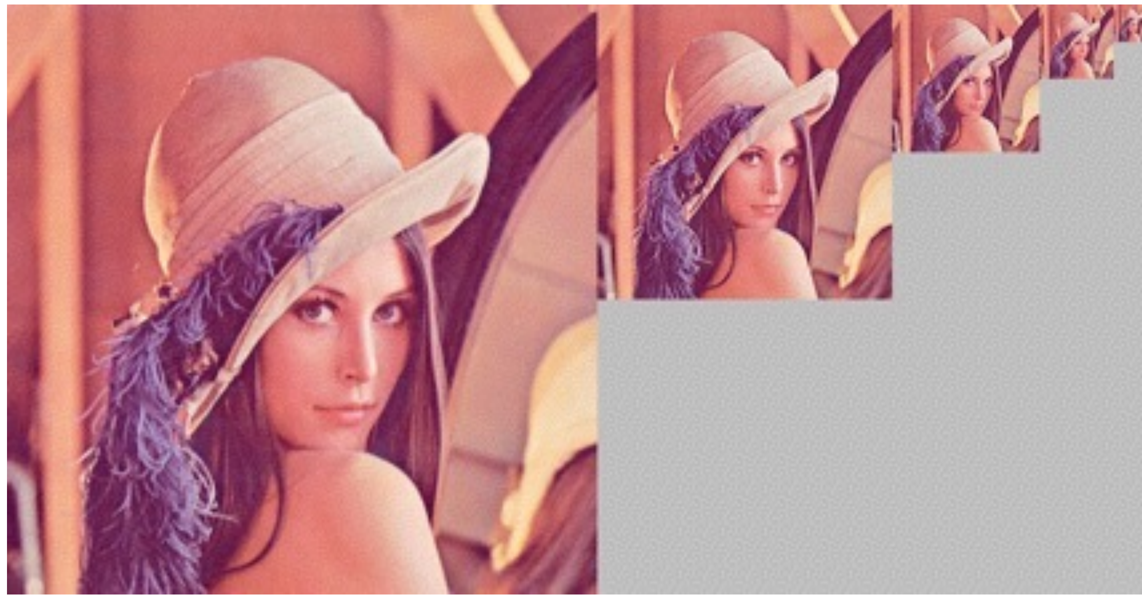
http://upload.wikimedia.org/wikipedia/commons/0/04/UVMapping.png



http://en.wikipedia.org/wiki/File:Cube_Representative_UV_Unwrapping.png

Texture Filtering

- During rasterization, for each rendered pixel of the textured object we need to look up a color value from the texture
  - will almost always fall between texture pixels (texels)
  - texture may have too much resolution: sampling or integration
  - texture may have too little resolution: interpolation
- naive approach: pick the nearest neighbor pixel
  - leads to blocky textures
- better approach: bilinear filtering
  - pick the 4 neighboring pixels and linearly interpolate



http://wiki.aqsis.org/dev/texture_filtering

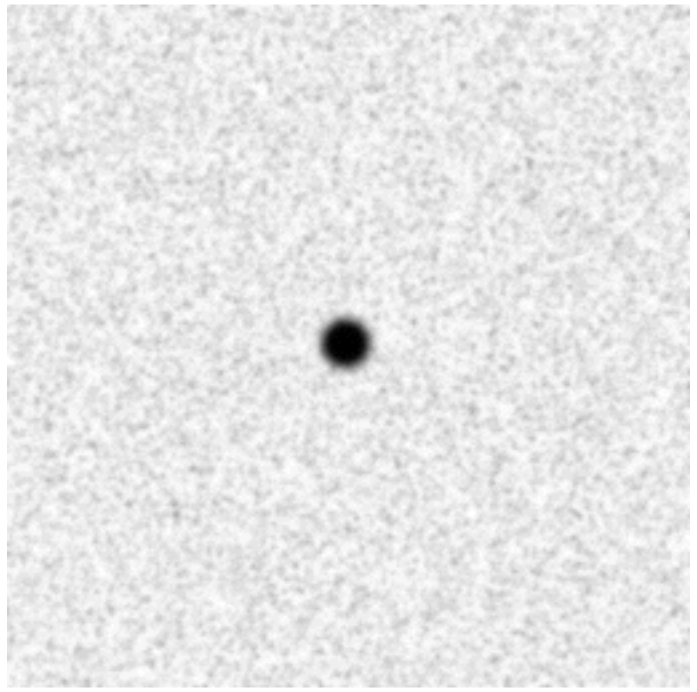
- Mip map: image pyramid with image scaled to 1/4 area in each step
  - eliminates excessive integration over pixels
- trilinear filtering: find the 2 best levels of the mip map and interpolate within and between them

Bump Mapping

- texture file is only greyscale
- grey value determines the elevation of the surface
  - e.g., black = dent, white = bulge

- can simulate complex 3D surface structure on very simple geometry
- often used together with image maps to enhance realism
- only modifies surface color, not silhouette!

- introduced by Jim Blinn in 1978
  - related and improved techniques with similar look in use today: normal mapping, displacement mapping



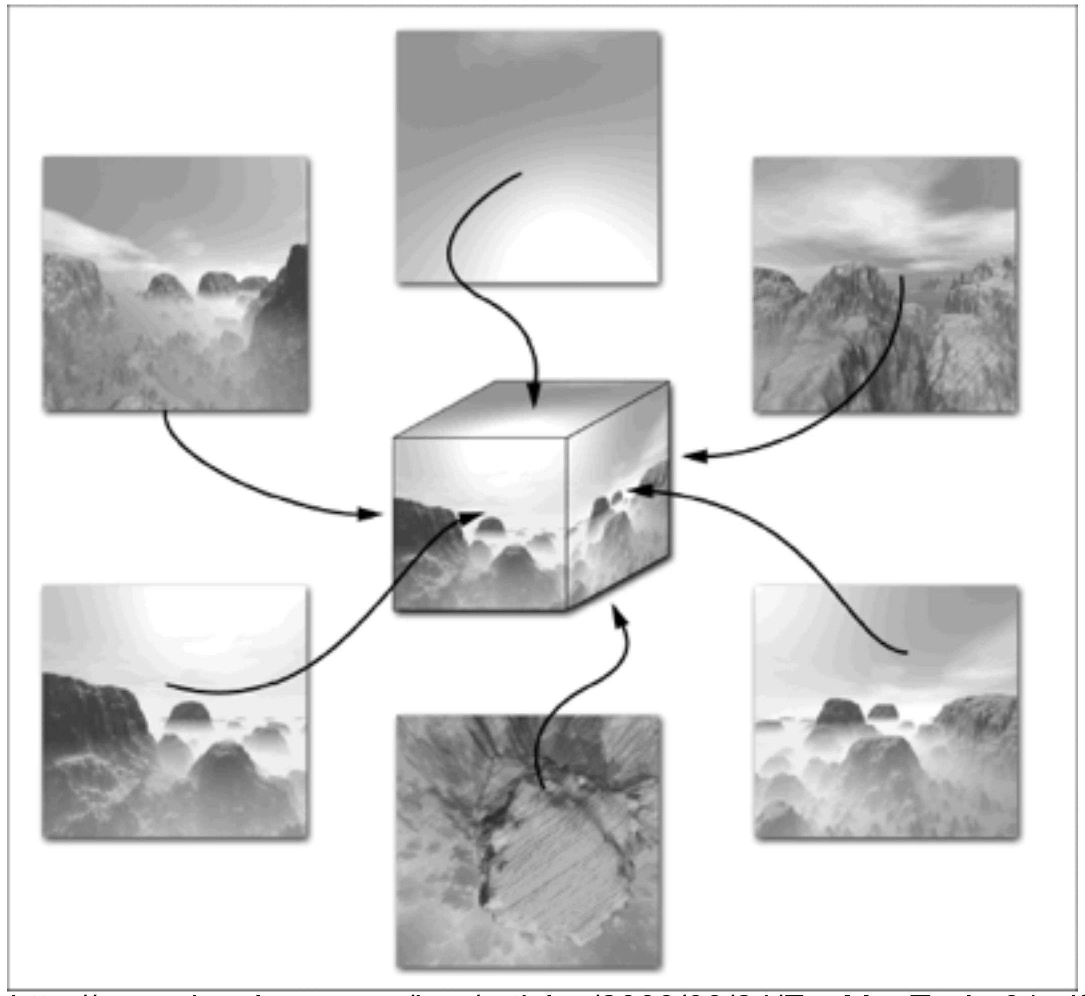
http://en.wikipedia.org/wiki/Bump_mapping

Environment Maps

- maps show the environment of the object
  - inside out view, 360 degrees in all directions
  - can be represented as 6 sides of a cube
  - can be photographed in a real environment

- can be used to calculate appropriate reflections
  - problem: ___________________________________

- can also be used for lighting
  - record map in real environment
  - light a 3D model with it
  - this model will seem as if lit in the real environment
  - useful for combining real and virtual objects



http://www.developer.com/img/articles/2003/03/24/EnvMapTecIm01.gif

http://tfc.duke.free.fr/

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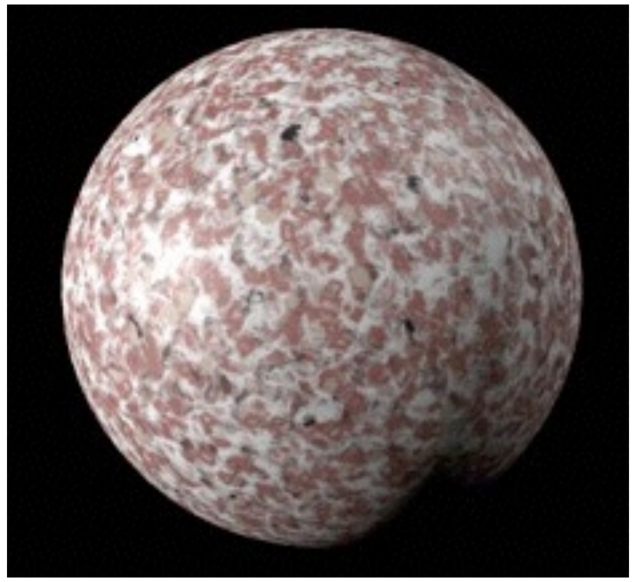
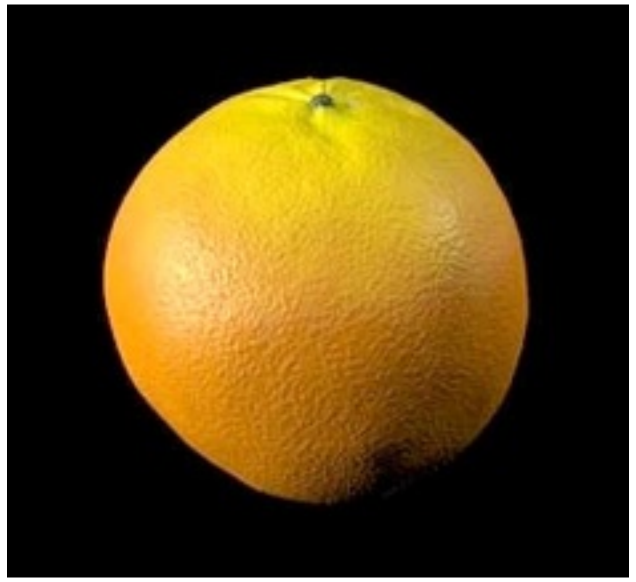
Procedural Surface Descriptions

- programming languages for surface descriptions
- can influence various stages of the rendering pipeline
  - in particular: can implement textures and the phong model
  - but also much more...
- can describe real 3D structures
  - not just surface color
- state of the art in high end 3D graphics
  - e.g., RenderMan, used in PIXAR movies
  - also in OpenGL, DirectX
- detailed implementation varies depending on the platform
- in OpenGL: vertex shaders and fragment shaders
  - fragments = parts of an object that cover 1 screen pixel





https://renderman.pixar.com/products/tools/rms-slim.html

OpenGL: Vertex and Fragment Shaders

- A vertex shader can do the following:
  - transform the vertex position using the modelview and projection matrices
  - transform normals, and if required normalize them
  - generate and transform texture coordinates
  - lighting per vertex or compute values for lighting per pixel
  - color computation
- A fragment shader can do the following:
  - compute colors, and texture coordinates per pixel
  - apply a texture
  - fog computation
  - compute normals if you want lighting per pixel

- This, and more details at: http://www.lighthouse3d.com/opengl/glsl/

Links, Various

- You‘ve been doing 3DCG too long if ...when people ask you, "What's up?", you reply "Y": http://www.deakin.edu.au/~agoodman/scc308/toolong.html

- Detailed class material from one of the world‘s leading groups: http://graphics.stanford.edu/courses/
- Compact overviews from the wisdom of the masses ;-): http://en.wikipedia.org/wiki/Rendering_(computer_graphics)

- Kajiya, James T. (1986), "The rendering equation", Siggraph 1986: 143, doi:10.1145/15922.15902

- Some nice tutorials related to this class: http://www.lighthouse3d.com/