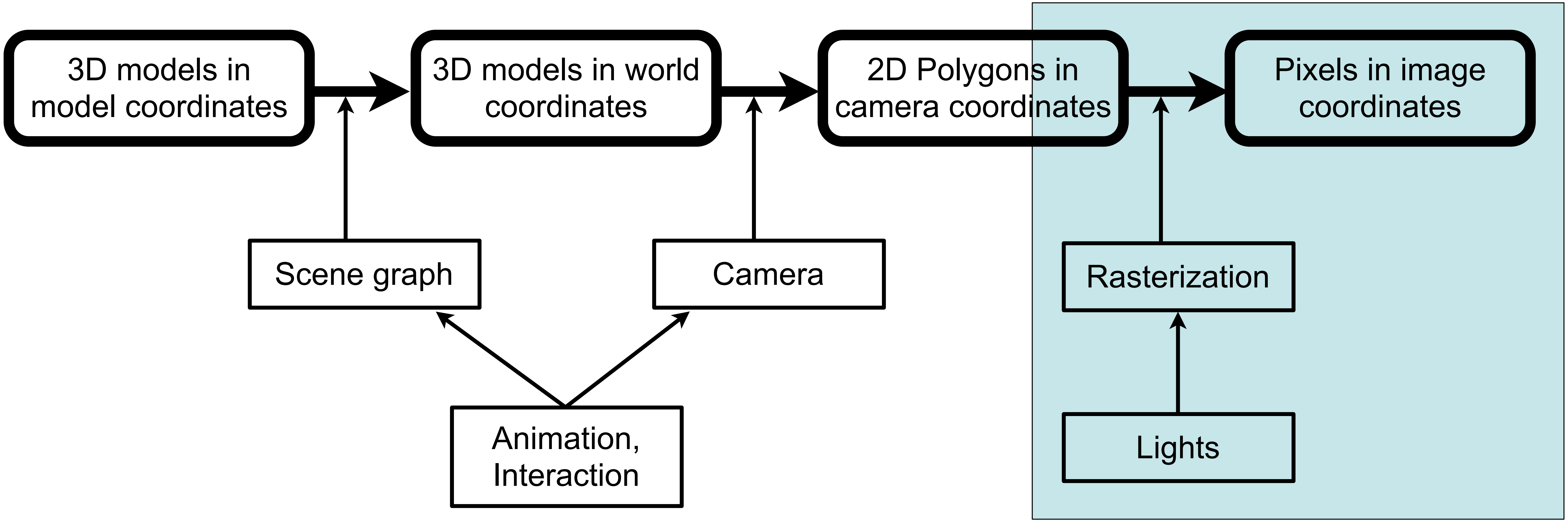
Chapter 7 - Shading and Rendering

- Local Illumination Models: Shading
- Global Illumination: Ray Tracing
- Global Illumination: Radiosity
- Non-Photorealistic Rendering

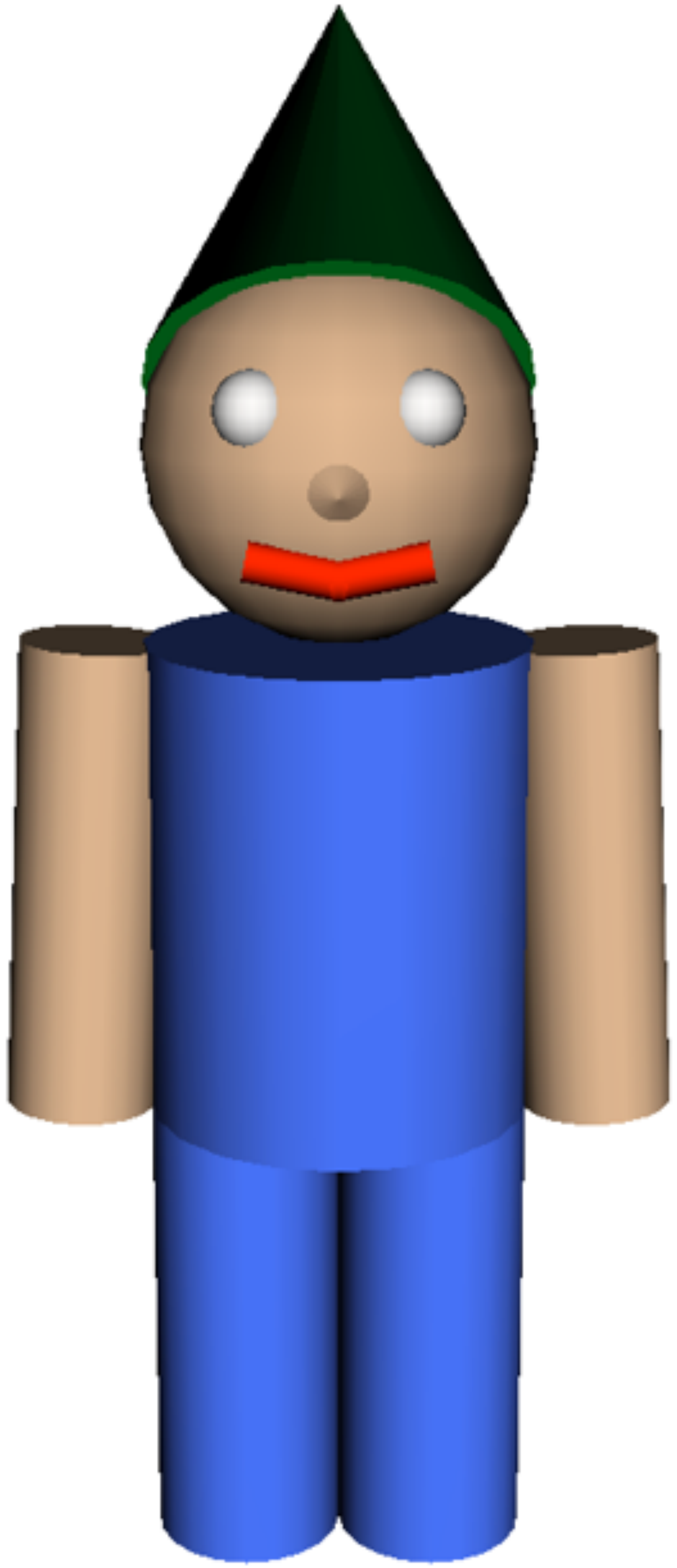
Literature: H.-J. Bungartz, M. Griebel, C. Zenger: Einführung in die Computergraphik, 2. Auflage, Vieweg 2002

The 3D rendering pipeline (our version for this class)



Local Illumination: Shading

- Local illumination:
  - Light calculations are done **locally** without the global scene
  - No cast shadows
    (since those would be from other objects, hence **global**)
  - Object shadows are OK, only depend on the surface normal



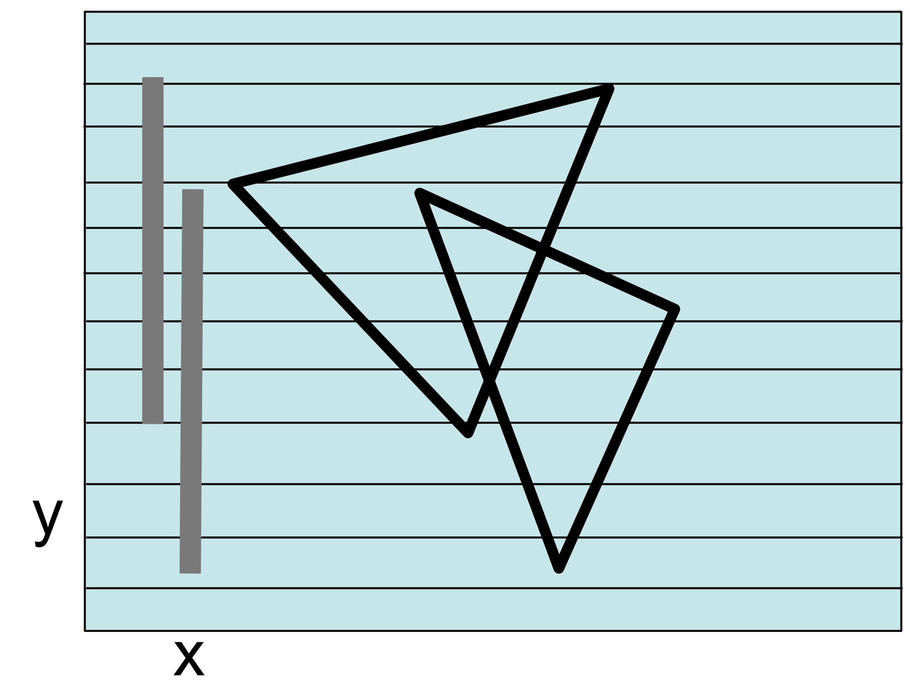
- Simple idea: Loop over all polygons
- For each polygon:
  - Determine the pixels it occupies on the screen and their color
  - Draw using e.g., Z-buffer algorithm to get occlusion right
- Each polygon only considered once
- Some pixels considered multiple times
- More efficient: Scan-line algorithms

Scan-Line Algorithms in More Detail

- Polygon Table (PT):
  - List of all polygons with plane equation parameters, color information and inside/outside flag (see rasterizaton)

- Edge Table (ET):
  - List of all non-horizontal edges, sorted by *y* value of top end point
  - including a reference back to polygons to which the edge belongs

- Active Edge Table (AET):
  - List of all edges crossing the current scan line, sorted by x value

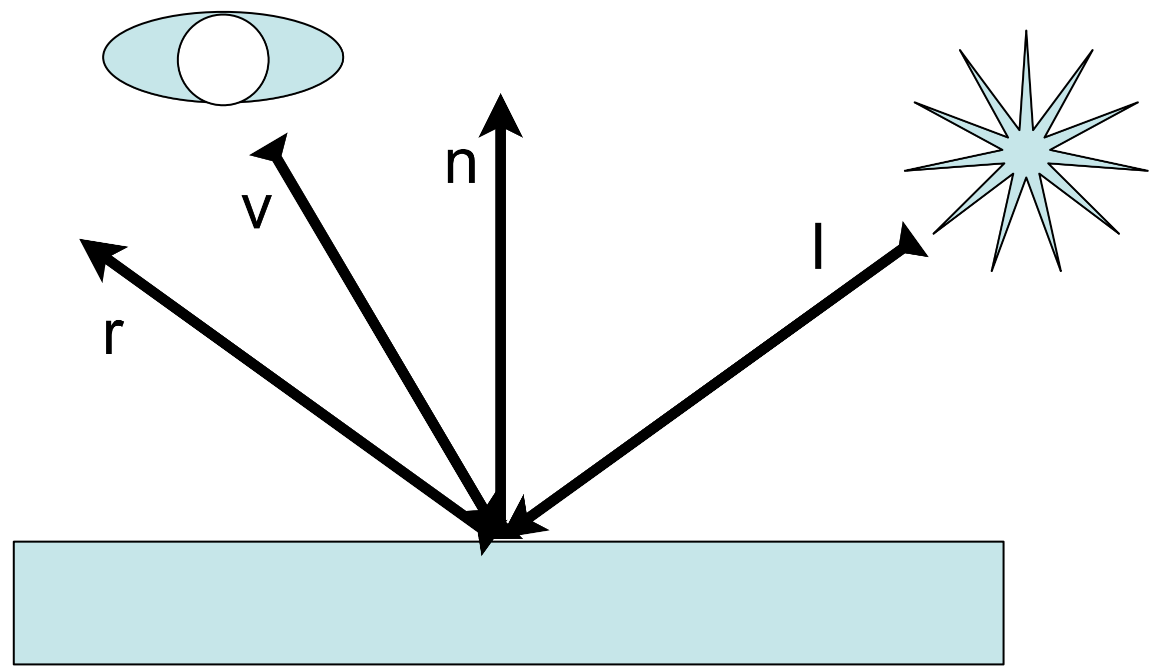



```
for v = 0..V (all scan lines):
    Compute AET, reset flags in PT;
    for all crossings in AET:
        update flags;
        determine currently visible polygon P (Z-buffer);
        set pixel color according to info for P in PT;
    end
end
```

- Each polygon considered only once
- Each pixel considered only once

Reminder: Phong's Illumination Model

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



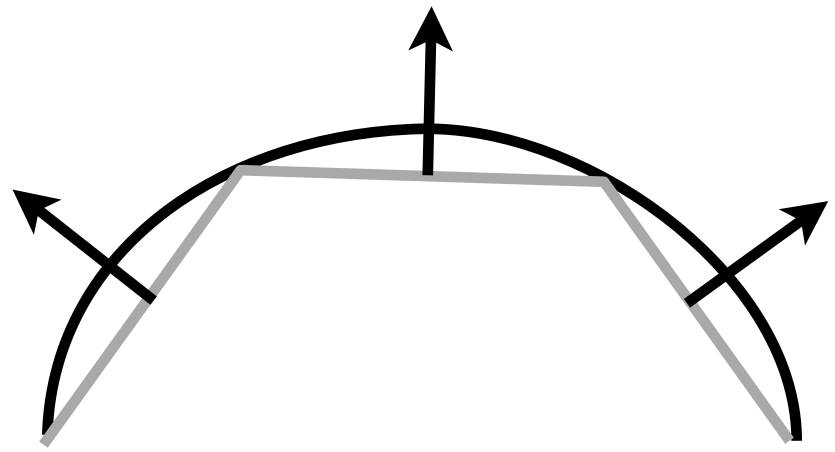
- Prerequisites for using the model:
  - Exact location on surface known
  - Light source(s) known
- Generalization to many light sources:
  - Summation of all diffuse and specular components created by all light sources
- Light colors easily covered by the model
- Do we really have to compute the formula for each pixel?

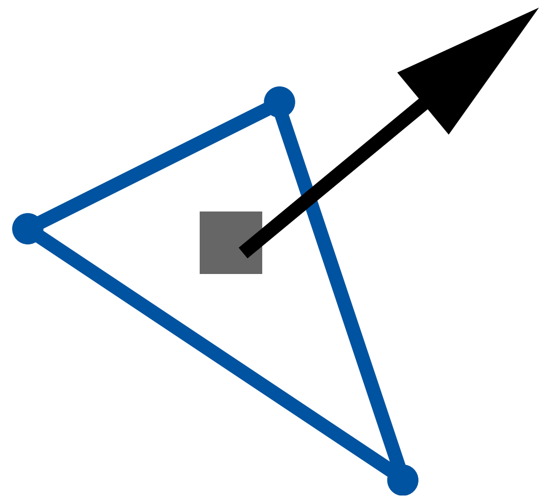
Flat Shading

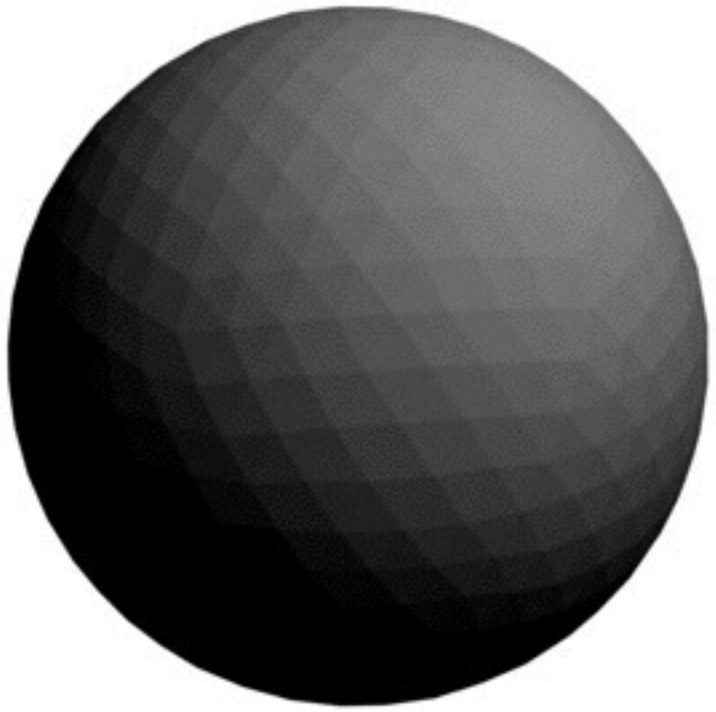
- Determine one surface normal for each triangle
- Compute the color for this triangle
  - using e.g., the Phong illumination model
  - usually for the center point of the triangle
  - using the normal, camera and light positions
- Draw the entire triangle in this color

- Neighboring triangles will have different shades
- Visible „crease“ between triangles

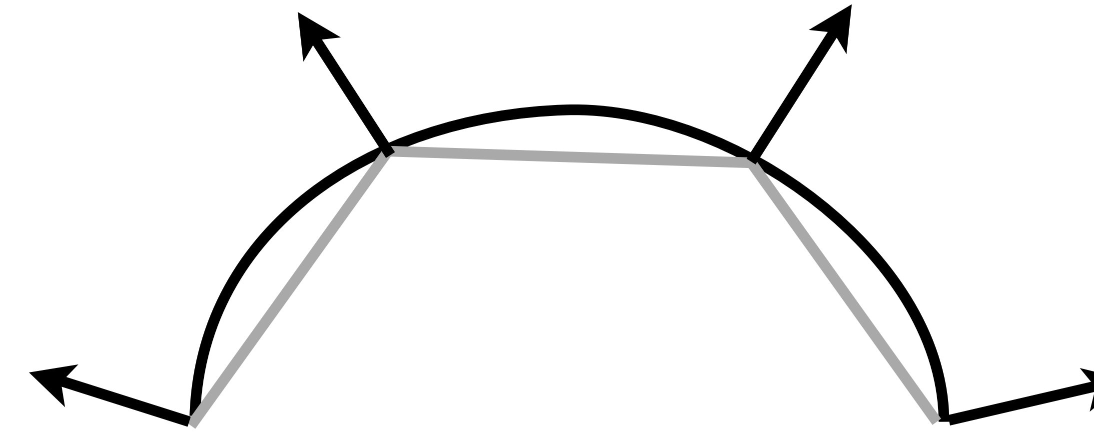
- Cheapest and fastest form of shading
- Can be a wanted effect, e.g., with primitives



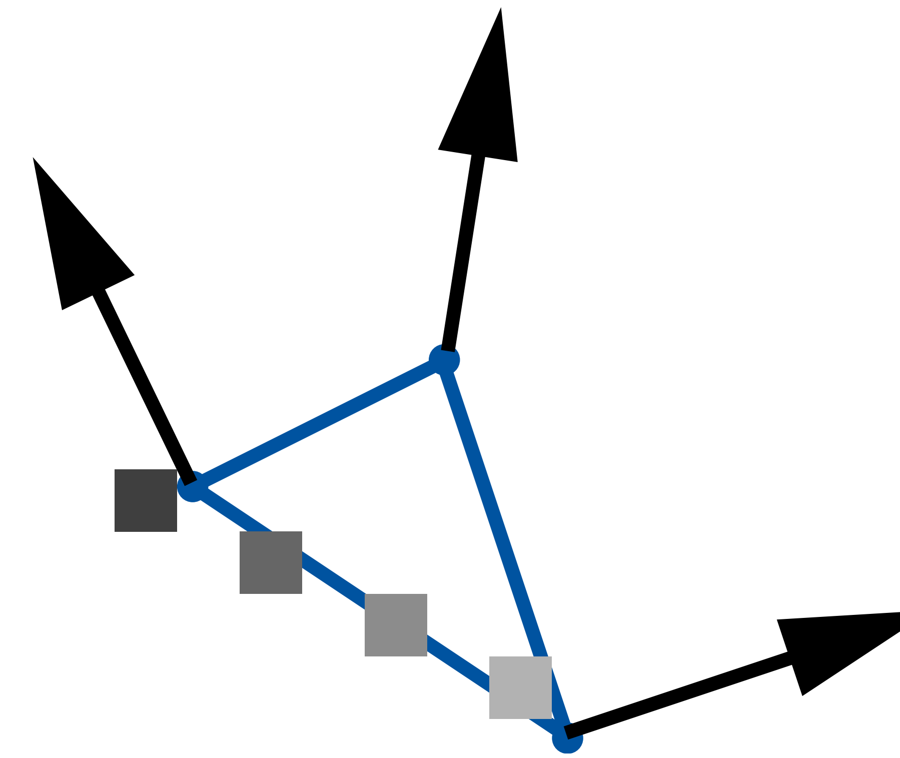




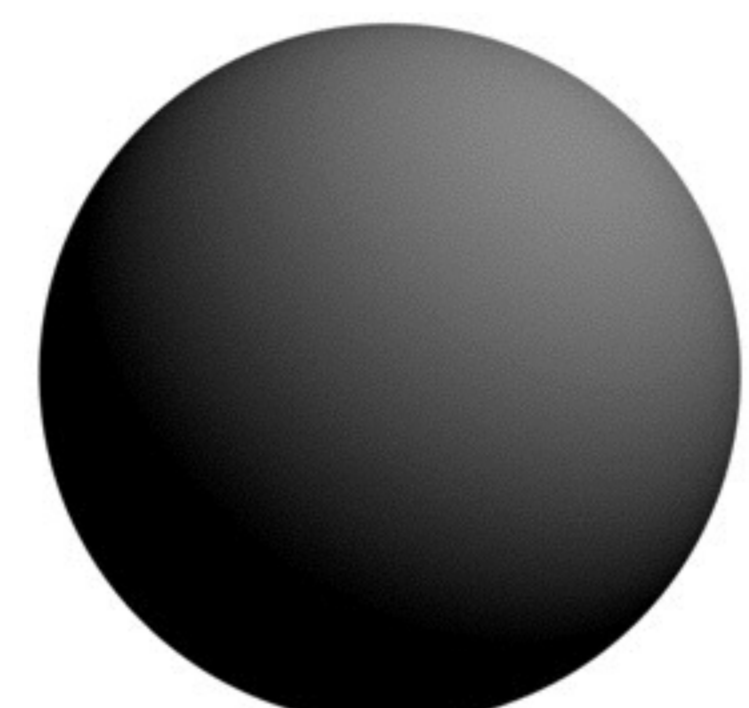
Gouraud Shading



- Determine normals for all mesh vertices
  - i.e., triangle now has 3 normals
- Compute colors at all vertices
  - using e.g., the Phong illumination model
  - using the 3 normals, camera and light positions
- Interpolate between these colors along the edges
- Interpolate also for the inner pixels of the triangle

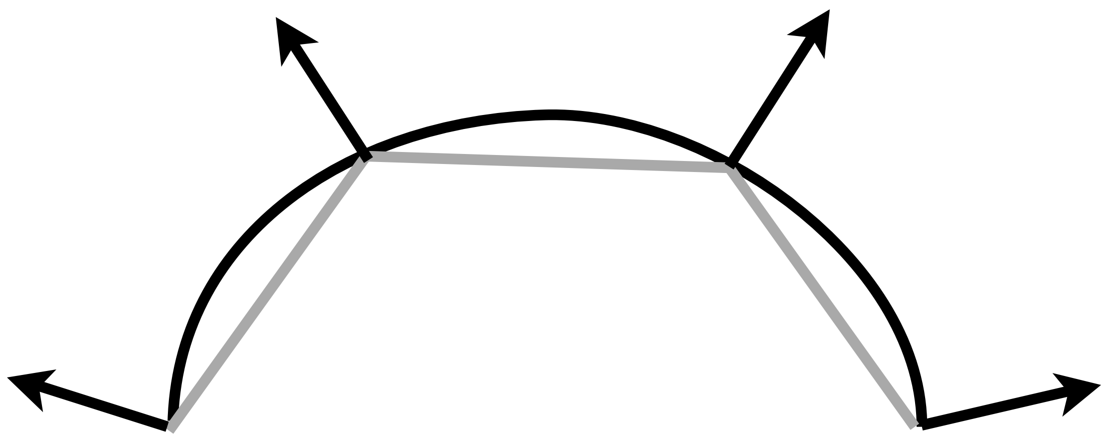


- Neighboring triangles will have smooth transitions
  - If normals at a vertex are the same for all triangles using it

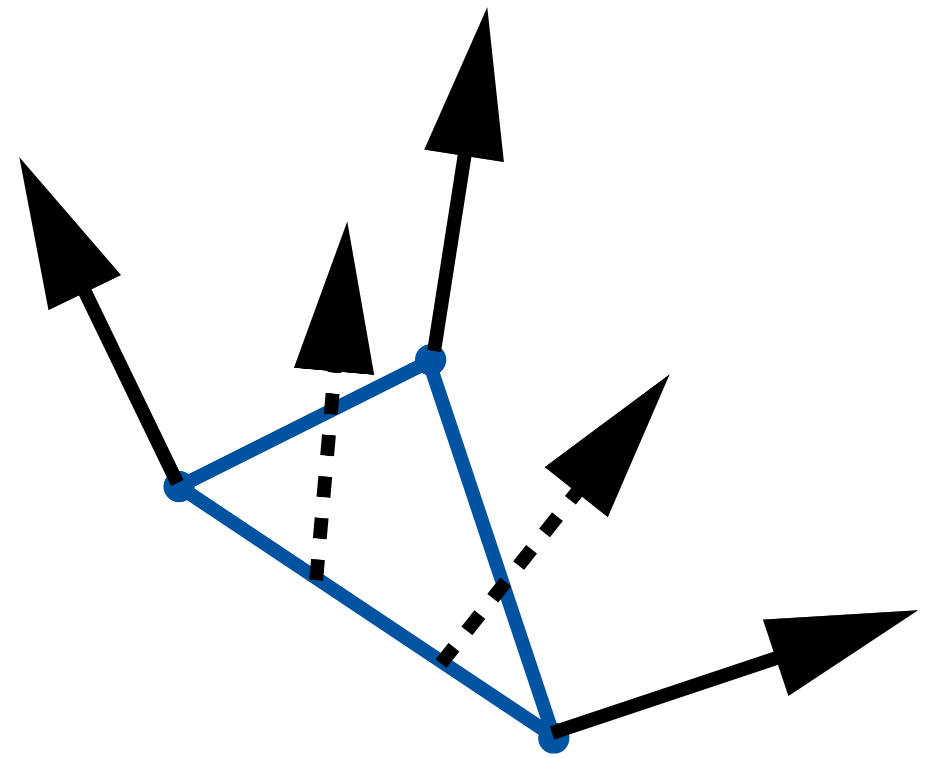


- Simplest form of smooth shading
  - Specular highlights only if they fall on a vertex by chance

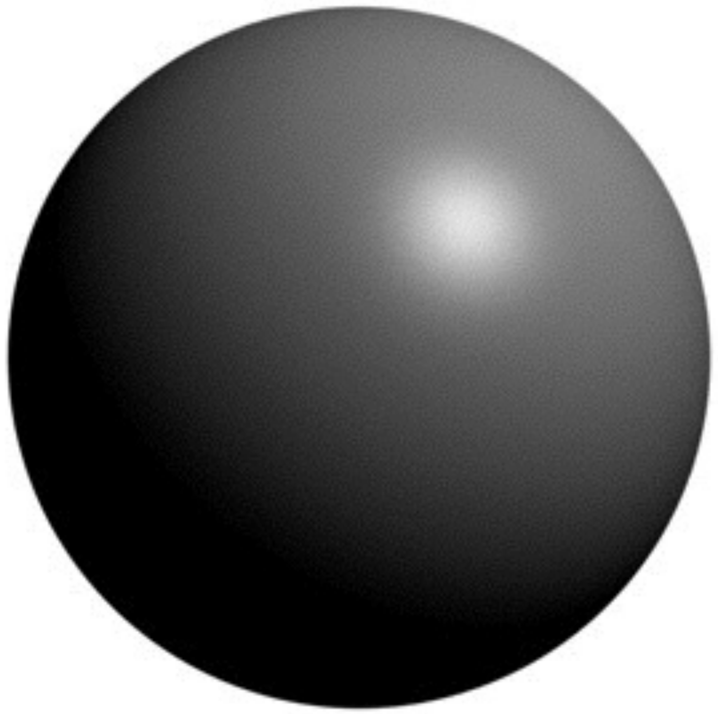
Phong Shading



- Determine normals for all mesh vertices
- Interpolate between these normals along the edges



- Compute colors at all vertices
  - using e.g., the Phong illumination model
  - using the interpolated normal, camera and light positions
- Neighboring triangles will have smooth transitions
  - If normals at a vertex are the same for all triangles using it



- Has widely substituted Gouraud shading
  - Specular highlights in arbitrary positions
  - Have to compute Phong illumination model for every pixel

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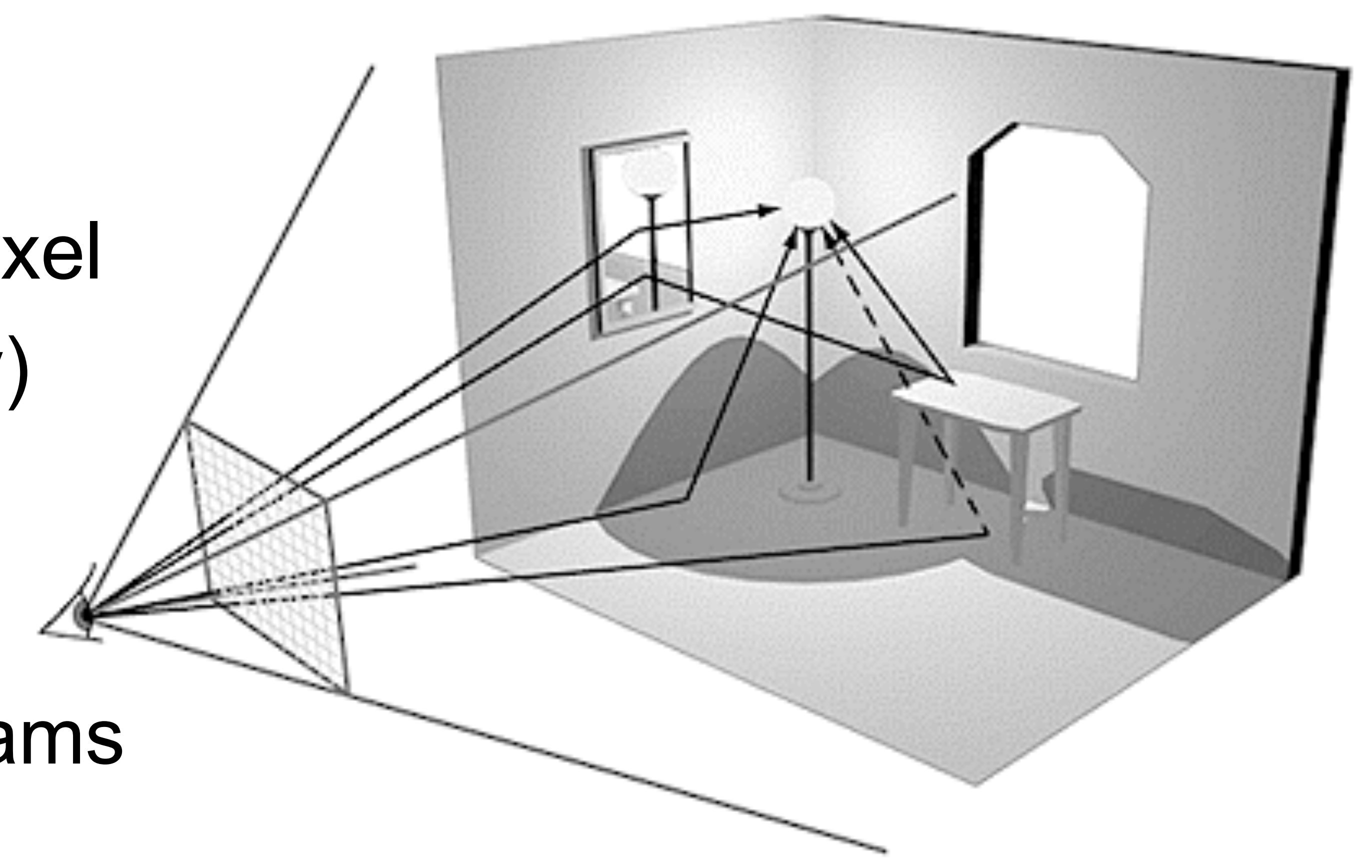
Global illumination: Ray Tracing

- Global illumination:
  - Light calculations are done **globally** considering the entire scene
  - i.e. cast shadows are OK if properly calculated
  - Object shadows are OK anyway

- Ray *casting*:
  - From the eye, cast a ray through every screen pixel
  - Find the first polygon it intersects with
  - Determine its color at intersection and use for the pixel
  - Also solves occlusion (makes Z-Buffer unnecessary)

- Ray *tracing*: recursive ray casting
  - From intersection, follow reflected and refracted beams
  - up to a maximum recursion depth
  - Works with arbitrary geometric primitives



http://pclab.arch.ntua.gr/03postgra/mladenstamenico/ (probably not original)

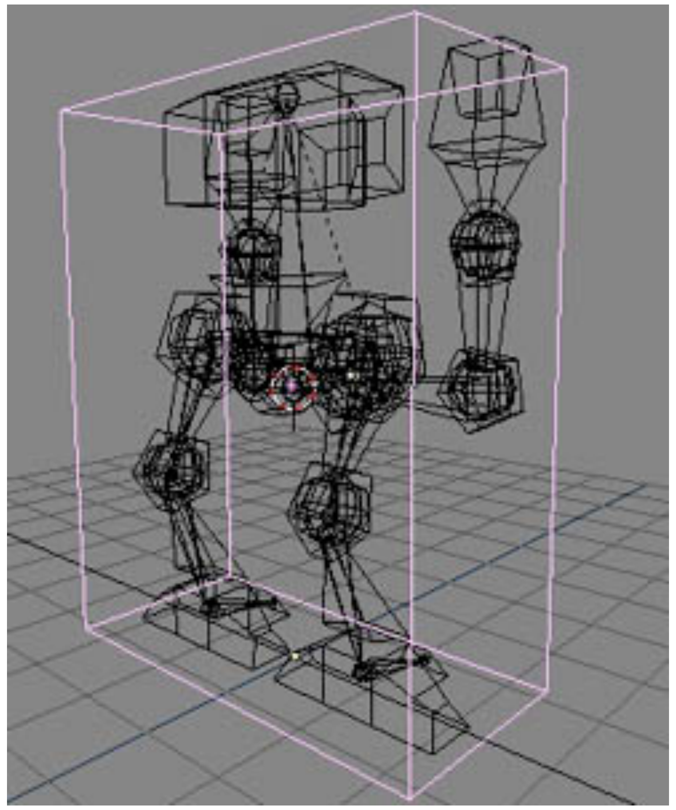
http://hof.povray.org/glasses.html

source: Blender Gallery


source: Blender Gallery

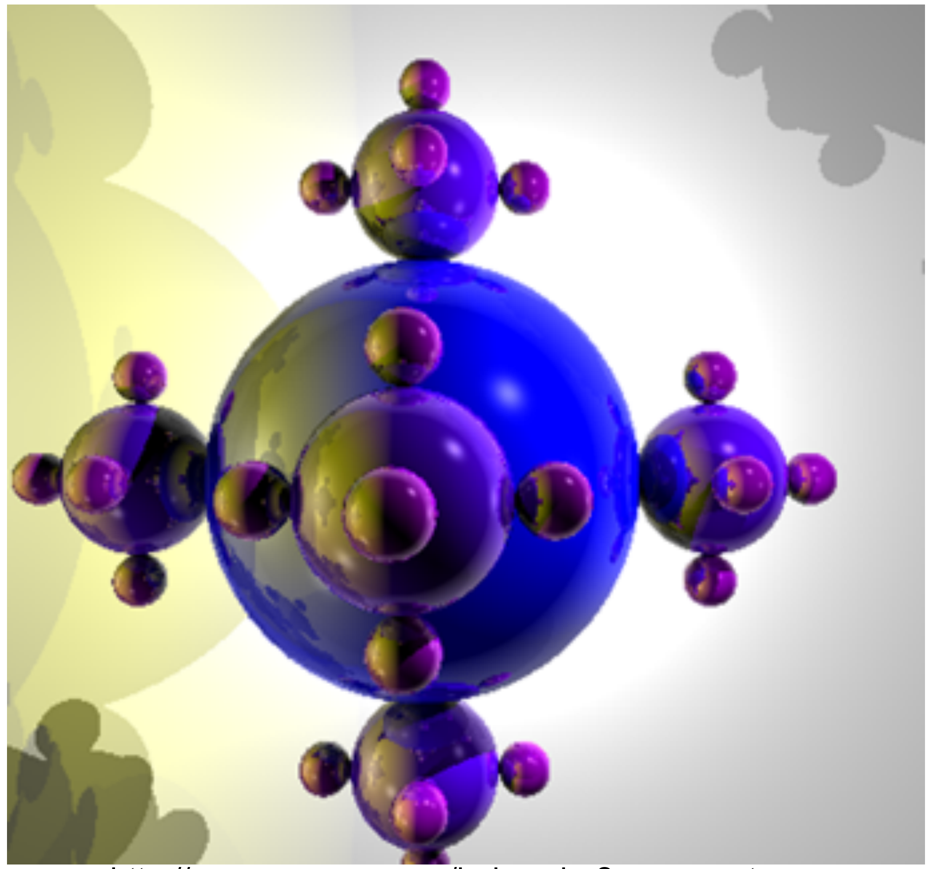
Brainstorming: What Makes Ray Tracing Hard?

Optimizations for Ray Tracing



https://sites.google.com/site/axeltp28/bounding-box

- Bounding volumes:
  - Instead of calculating intersection with individual objects, first calculate intersection with a volume containing several objects
  - Can decrease computation time to less than linear complexity (in number of existing objects)
- Adaptive recursion depth control
  - Maximum recursion limit is not always necessary
  - Recursion should be stopped as soon as possible
  - E.g., stop if intensity change goes below a threshold value

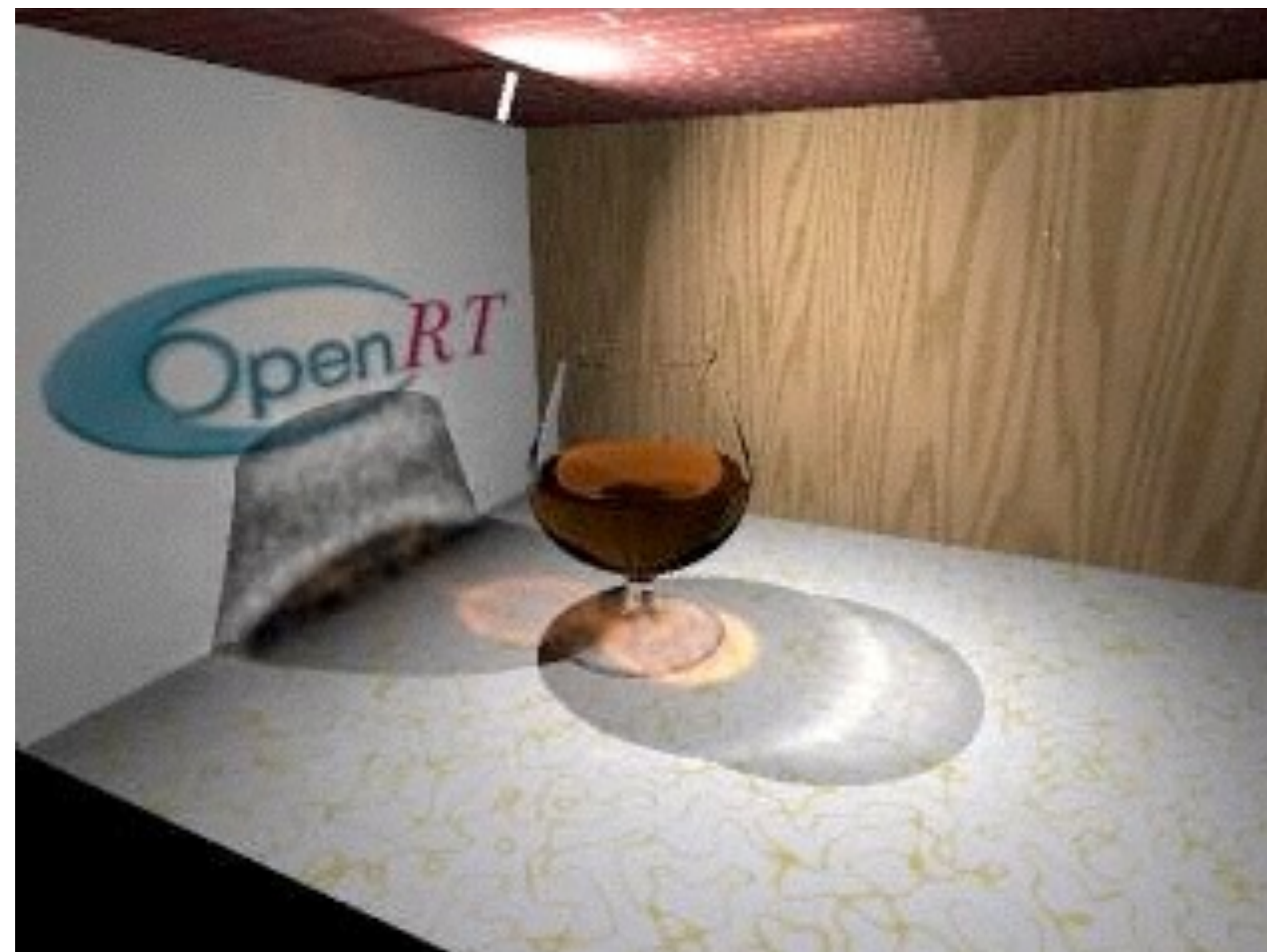


http://www.emeyex.com/index.php?page=raytracer

- Monte Carlo Methods
  - Improve complexity (cascading recursion = exponential)
  - Use ***one*** random ray for recursive tracing (instead of refracted/reflected rays)
  - Carry out multiple experiments (e.g. 100) and compute average values

Recent (2007) development: Real Time Ray Tracing

- Various optimizations presented over the last few years
- Real time ray tracing has become feasible
- Used to be http://openrt.de/ (images from there, now dead)



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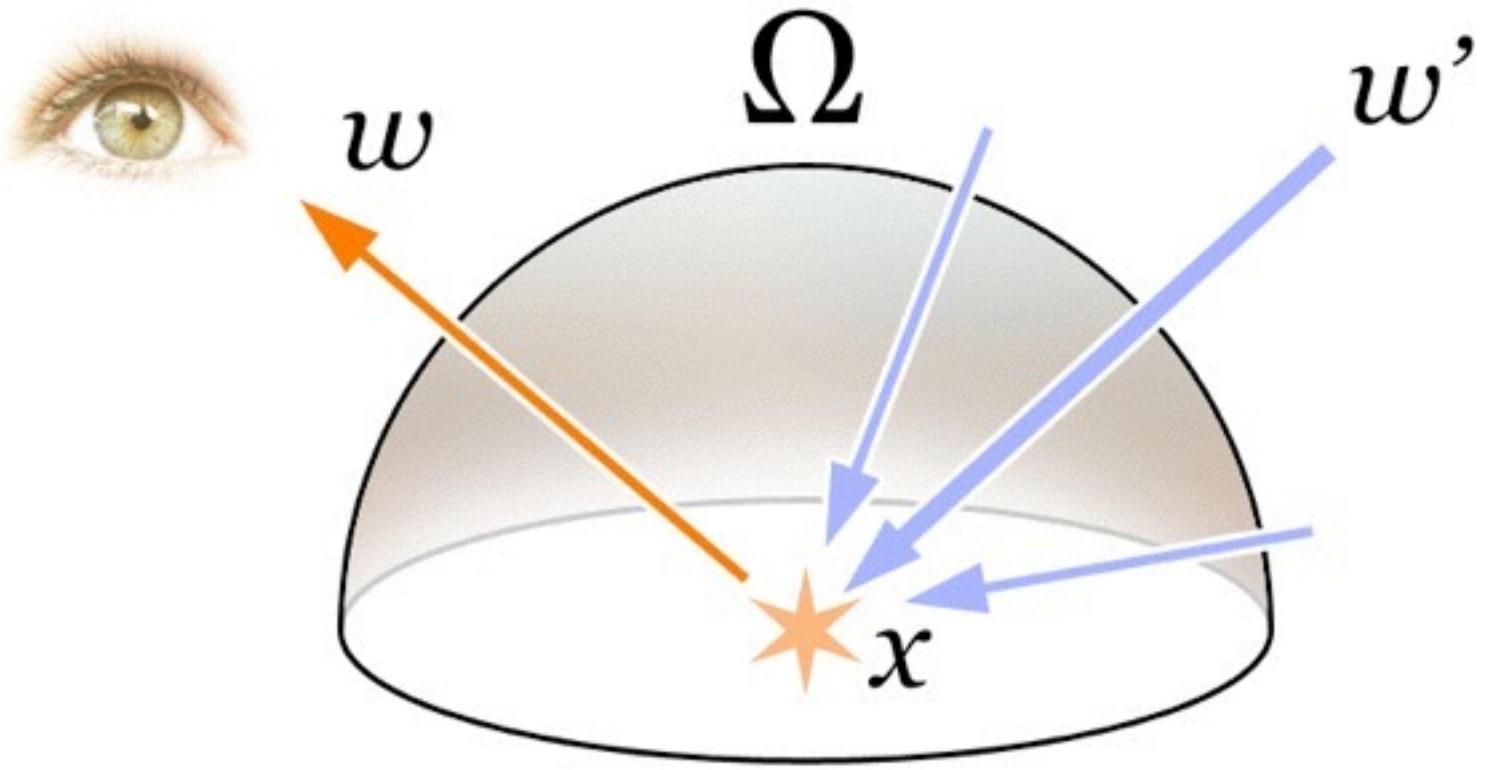
Reminder: The rendering equation [Kajiya '86]

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

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

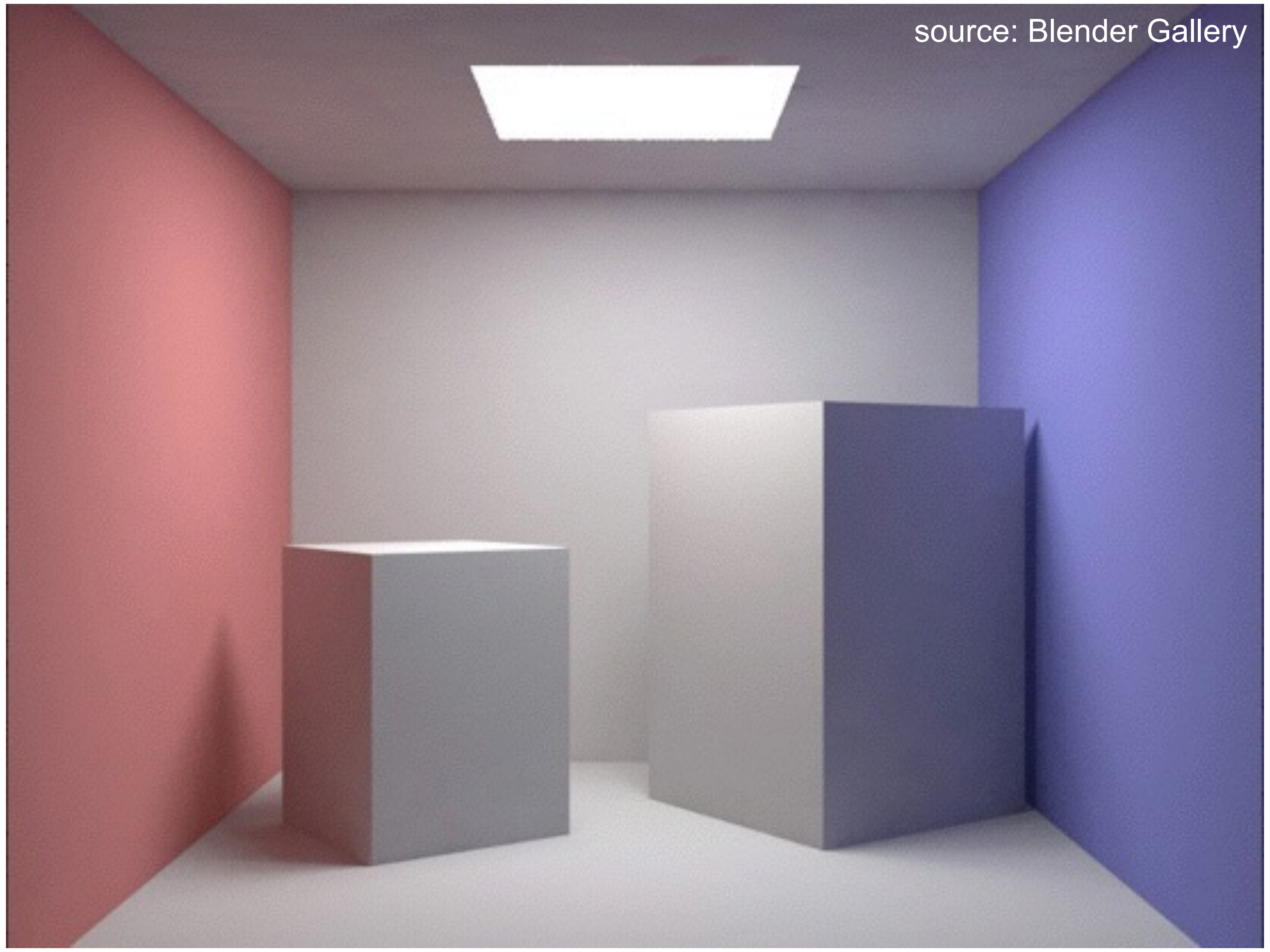


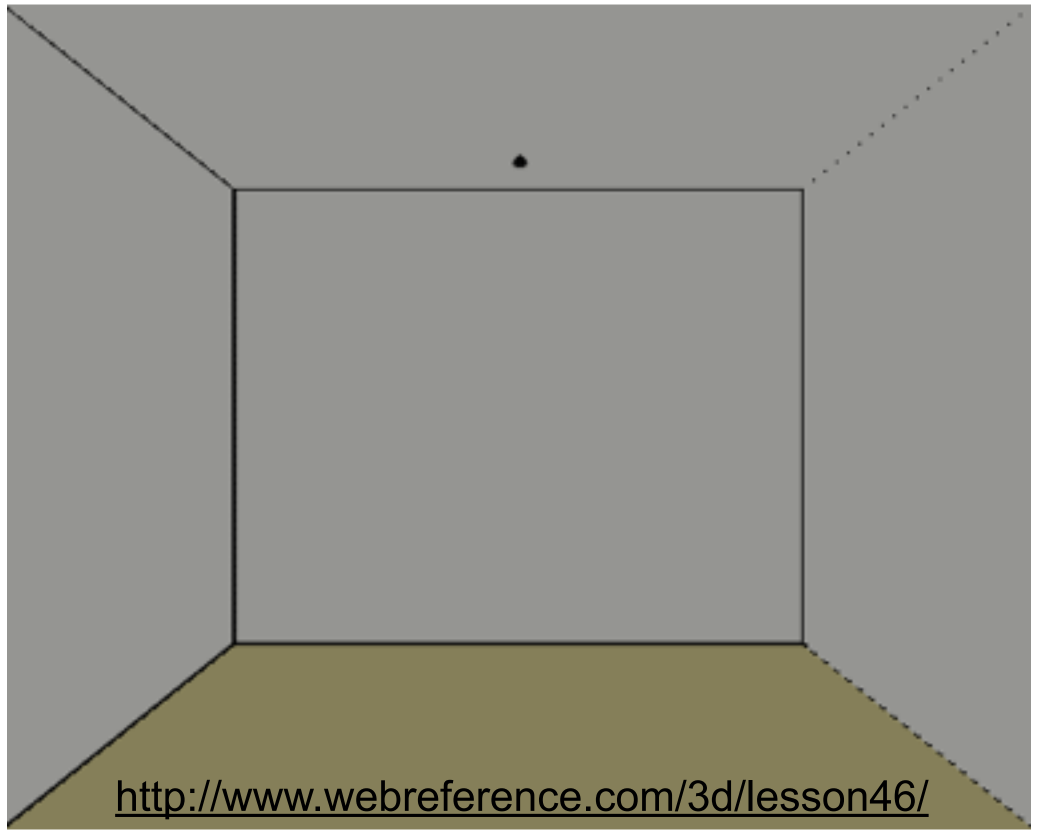
http://en.wikipedia.org/wiki/File:Rendering_eq.png

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

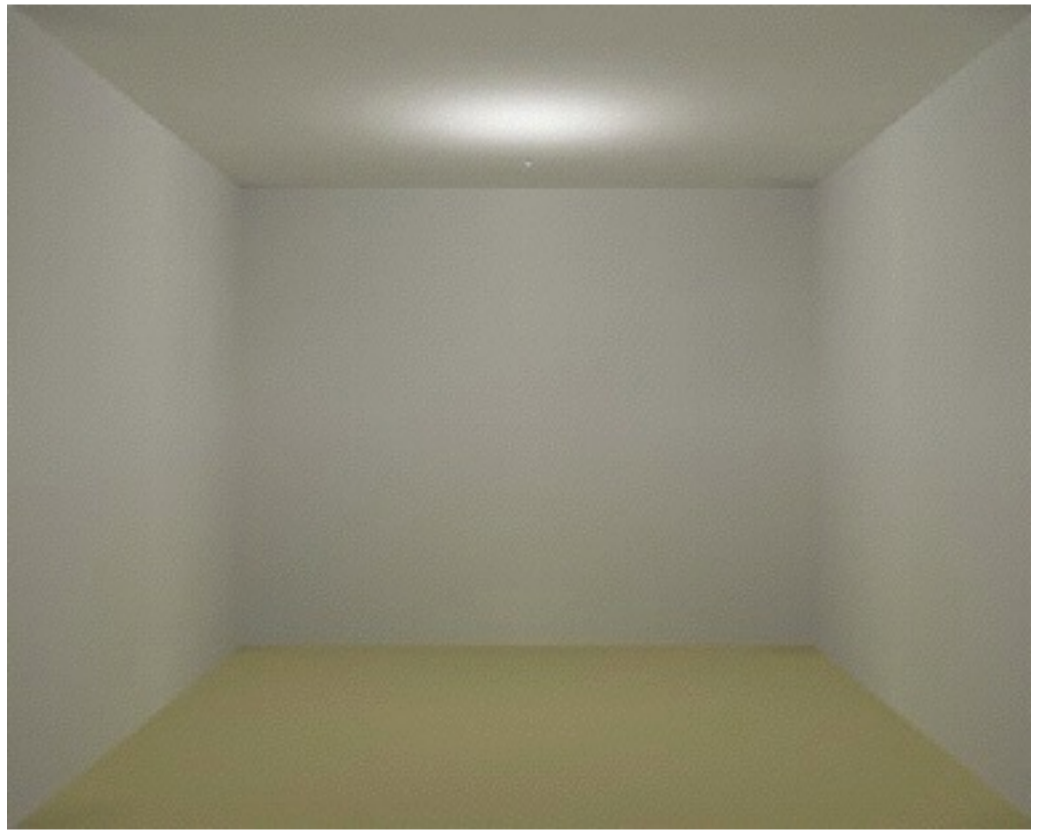
Global Illumination: Radiosity

- Simulation of energy flow in scene
- Can show „color bleeding“
  - blueish and reddish sides of boxes
- Naturally deals with area light sources
- Creates soft shadows
- Only uses diffuse reflection
  - does not produce specular highlights



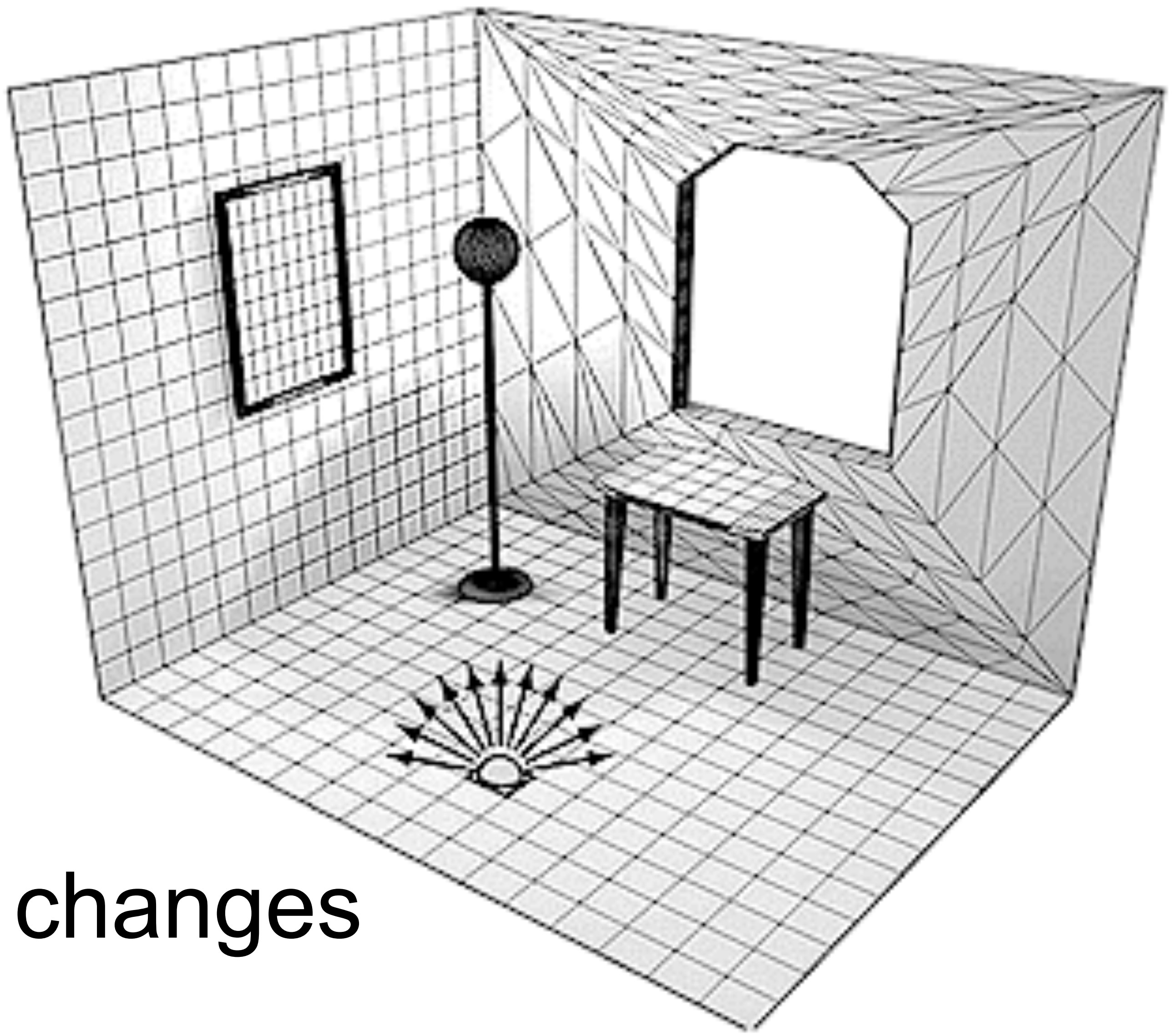


http://www.webreference.com/3d/lesson46/



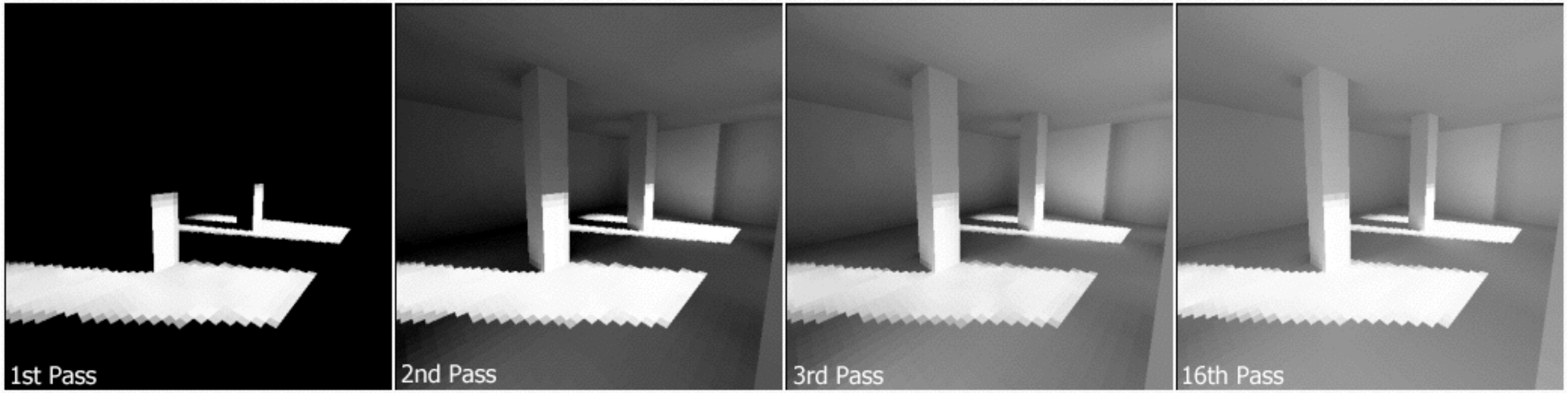
Radiosity Algorithm

- Divide all surfaces into small patches
- For each patch determine its initial energy
- Loop until close to energy equilibrium
  - Loop over all patches
    - determine energy exchange with every other patch
- „Radiosity solution“: energy for all patches
- Recompute if ______________________ changes



http://pclab.arch.ntua.gr/03postgra/mladenstamenico/ (probably not original)

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



source: Blender Gallery

Combinations

- Ray Tracing is adequate for reflecting and transparent surfaces
- Radiosity is adequate for the interaction between diffuse light sources
- What we want is a combination of the two!
  - This is non-trivial, a simple sequence of algorithms is not sufficient
- Example for a state-of-the-art “combination”
  (more like another innovative approach): *Photon Maps* (Jensen 96)
  - First step:
    Inverse ray tracing with accumulation of light energy
    Photons are sent from light sources into scene, using Monte Carlo approach
    Surfaces accumulate energy from various sources
  - Second step:
    “Path tracing” (i.e. Monte Carlo based ray tracing) in optimized version
    (e.g. only small recursion depth)

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Non-Photorealistic Rendering (NPR)

- Create graphics that look like drawings or paintings
- One method: stroke-based NPR
  - instead of grey shades, determine a stroke density and pattern
  - imitates pencil drawings or etchings (Kupferstich)
- Other methods: using image manipulation on rendered images
  - can in principle often be done in Photoshop
- Active field of research
  - http://www.cs.ucdavis.edu/~ma/SIGGRAPH02/course23/
  - http://graphics.uni-konstanz.de/forschung/npr/watercolor/
  - many others

http://www.cs.ucdavis.edu/~ma/SIGGRAPH02/course23/

http://www.katrinlang.de/npr/